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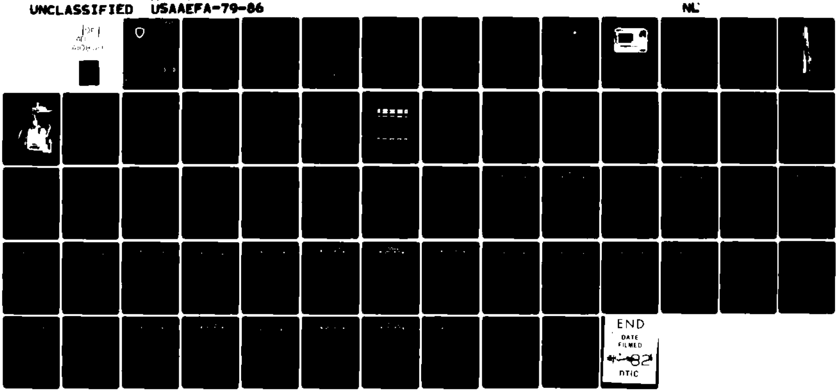

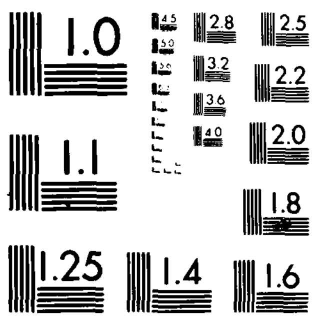

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963 A

USAAEFA PROJECT NO. 79-86

ICE PHOBICS BLADE TRACKING AND COMPARISON OF VIBRATION ANALYSIS TECHNIQUES

FINAL REPORT

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MAY 1981

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UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

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Vibration
VIBREX

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The United States Army Aviation Engineering Flight Activity conducted an evaluation of two vibration measuring devices, the Chadwick-Helmuth VIBREX and the Scientific-Atlanta Vibration Signature Recorder, as flight test instrumentation. During the course of those evaluations, it was determined that the Dow Corning E2460-40-1 (redesignated E2978-46) ice phobic coating applied to the rotor blades of a UH-1H helicopter, did not induce undesirable vibrations. It was also concluded that the VIBREX may be used as test instrumentation if the frequencies of interest are already known, and the Scientific-Atlanta device provides good "quick look" spectral vibration data.

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INTRODUCTION

BACKGROUND

1. In January 1978, the United States Army Aviation Engineering Flight Activity (USAAEFA) evaluated Dow Corning Corporation's E2460-40-1 ice phobic coating on the rotor blades of a UH-1H helicopter (Reference 1, Appendix A). The purpose of the coating is to provide a surface to which ice will not adhere. After the evaluation was completed, the helicopter developed intermittent one per revolution vibrations that maintenance personnel had difficulty removing. Speculation was that this vibration was related to the use of the ice phobic coating.

2. In June 1979, USAAEFA assigned its Advanced Methodology and Analysis Office to investigate any vibration problems associated with the coating. Also, during the investigation, an evaluation was to be made of two relatively new vibration measuring devices.

TEST OBJECTIVES

3. The objectives of this test were to

a. Determine if the Dow Corning E2460-40-1 ice phobic coating induces undesirable vibrations when applied to the main rotor blades of a UH-1H helicopter

b. Evaluate the effectiveness and accuracy of the Chadwick-Helmuth VIBREX Balancing Kit (hereafter referred to as VIBREX) as both a vibration sensor, and as an aid to balancing and tracking the main rotor

c. Evaluate the Scientific-Atlanta Vibration Signature Recorder (VSR) as a vibration measuring device

d. Compare the results of the two vibration measuring devices with results obtained from the USAAEFA spectral analyzer and with the newly written fast Fourier transform (FFT) computer program

e. Compare pilot's opinion of vibration severity using the Vibration Rating Scale (VRS) with data from the various recording devices.

DESCRIPTION

Aircraft

4. The test aircraft was a JUH-1H, US Army serial number 69-15532. Vibration data (accelerations) were recorded along with other aircraft parameters on the PCM track of the on-board tape recorder. Accelerations were also recorded on the FM track. A detailed description of the standard UH-1H is contained in the operators manual (Reference 2).

Ice Phobics

5. The Dow Corning E2460-40-1 (redesignated E2978-46) ice phobic coating is a cationic silicone base liquid with a viscosity comparable to that of SAE 10 weight oil. The coating may be applied using spray, brush, roller, etc. During this

evaluation, the coating was sprayed on and any irregularities were removed with a cloth.

VIBREX System

6. The VIBREX Balancing Kit, manufactured by Chadwick-Helmuth Company, Inc. of Monrovia, California is used to measure and indicate the level of vibrations induced by the main and tail rotors of a helicopter. The VIBREX analyzes the vibration caused by out-of-track, or out-of-balance; and then, by plotting vibration amplitude and peak amplitude azimuth (clock angle) on a chart, the amount and location of rotor track or weight changes can be determined.

7. The VIBREX system consists of two parts: the Balancer/Phazor, and the Strobex. The Balancer/Phazor is contained in a box 8.125 inches by 8.375 inches by 2.25 inches and weighs approximately 4 pounds (Figure 1). The key feature of this unit is a tuneable electronic bandpass filter which is tuned to reject all but one frequency of vibration under study. The meter reads the amplitude of vibration (in inches per second) at the frequency of concern. The Phazor section contains a phase meter that reads clock angle, or phase angle, relative to a one per revolution signal from the rotor and the vibration signal from an accelerometer.

8. The Strobex tracker (Figure 2) is a small (6.0 by 4.25 by 5 inches) hand held combination power supply and strobe flash tube weighing 5 pounds. It illuminates reflective targets on the tail rotor to measure tail rotor clock angle, or the main rotor to indicate rotor track and lead-lag. Further description of the VIBREX system is in Reference 3, and Appendix B.

Vibration Signature Recorder

9. The Vibration Signature Recorder Model 2538, is manufactured by the New Jersey Division, Scientific-Atlanta, Inc., of Randolph Township, New Jersey (Figure 3). The VSR is contained in a box 10.25 by 14.25 by 10 inches, and weighs 18 pounds. The signals from an accelerometer are fed into the recorder, and a plot of vibration velocity versus frequency is produced on a 4 by 6 inch card. The entire process takes approximately 60 seconds per accelerometer. A more detailed description is contained in Reference 4, and Appendix B.

TEST SCOPE

10. The flight evaluation was conducted at Edwards Air Force Base, California (2303 foot elevation) from June 1979 through March 1980. A total of 29.7 hours were flown. Typical flight conditions were as follows:

Main rotor speed	324 RPM
Longitudinal center of gravity	FS138 (Mid)
Density altitude	6000 ft
Gross weight	8000 lb
Indicated airspeed	0, 50, 80 and 100 knots

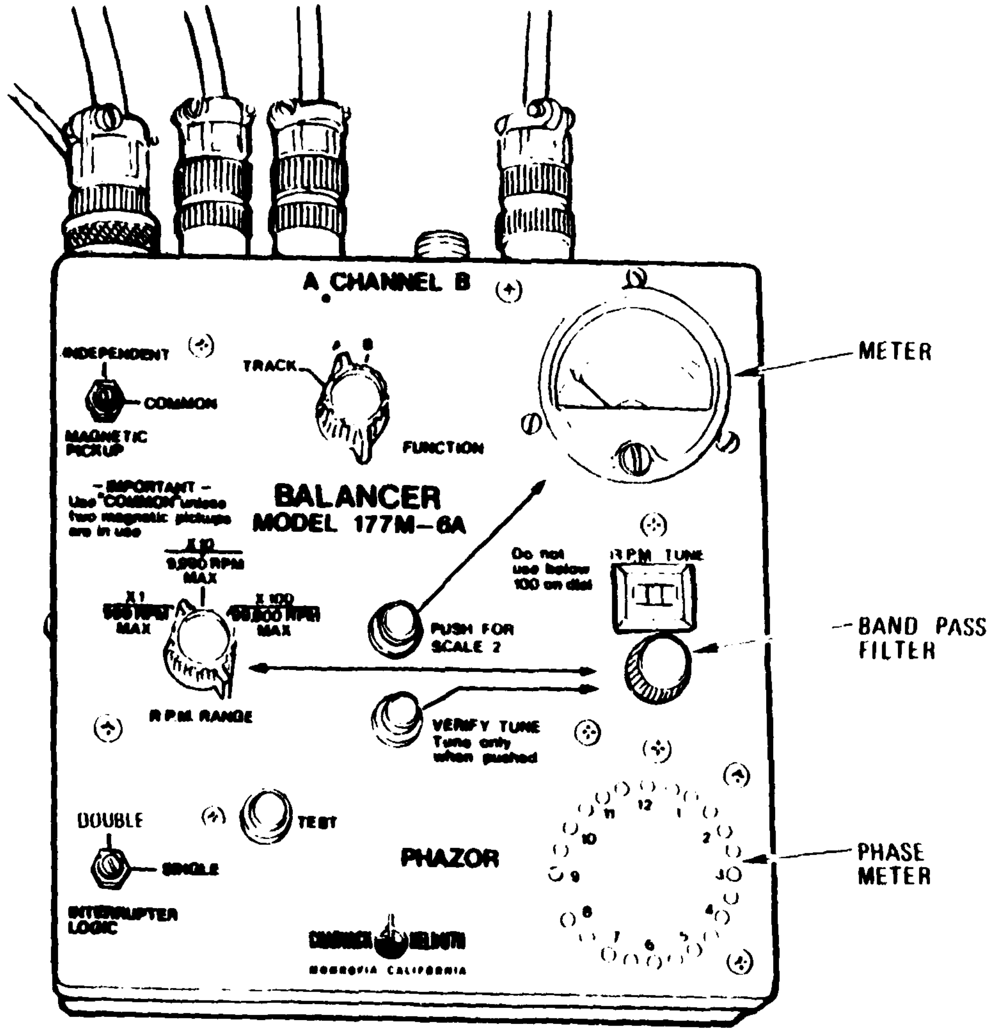


FIGURE 1. VIBREX BALANCER/PHAZOR

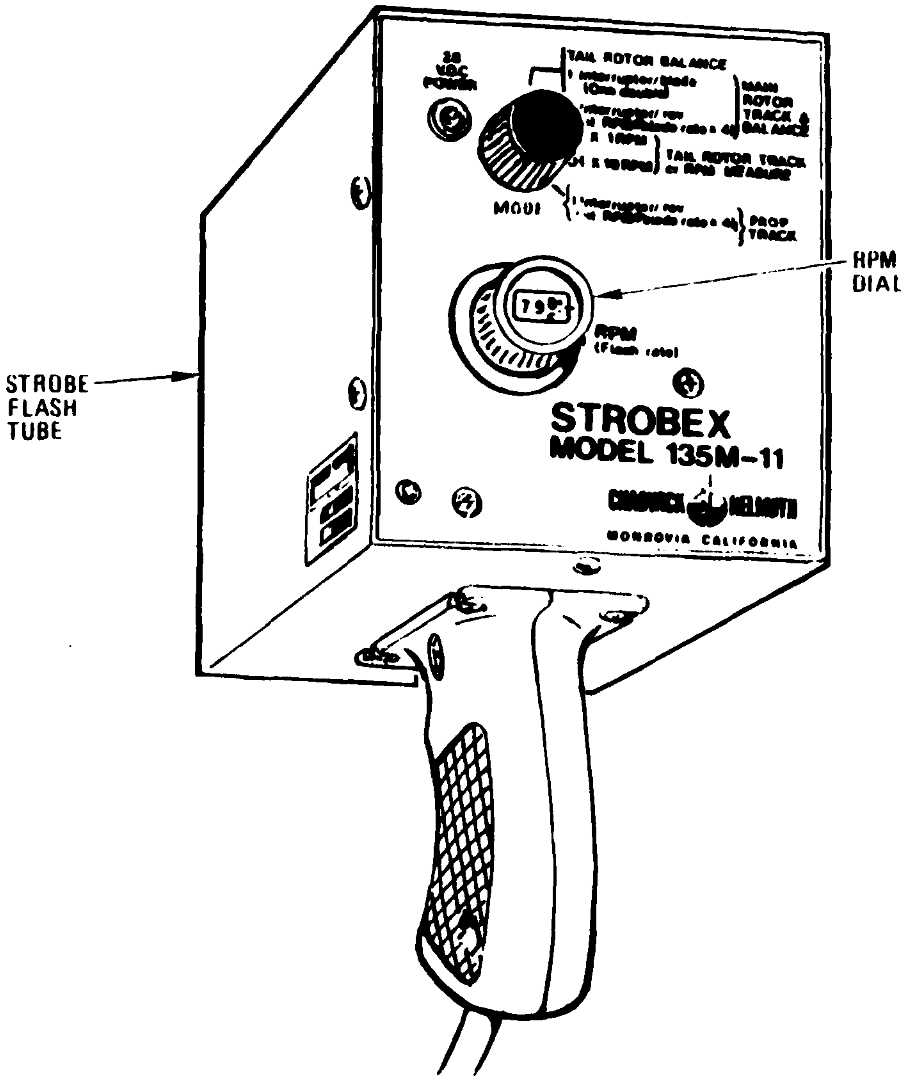


FIGURE 2. STROBEX

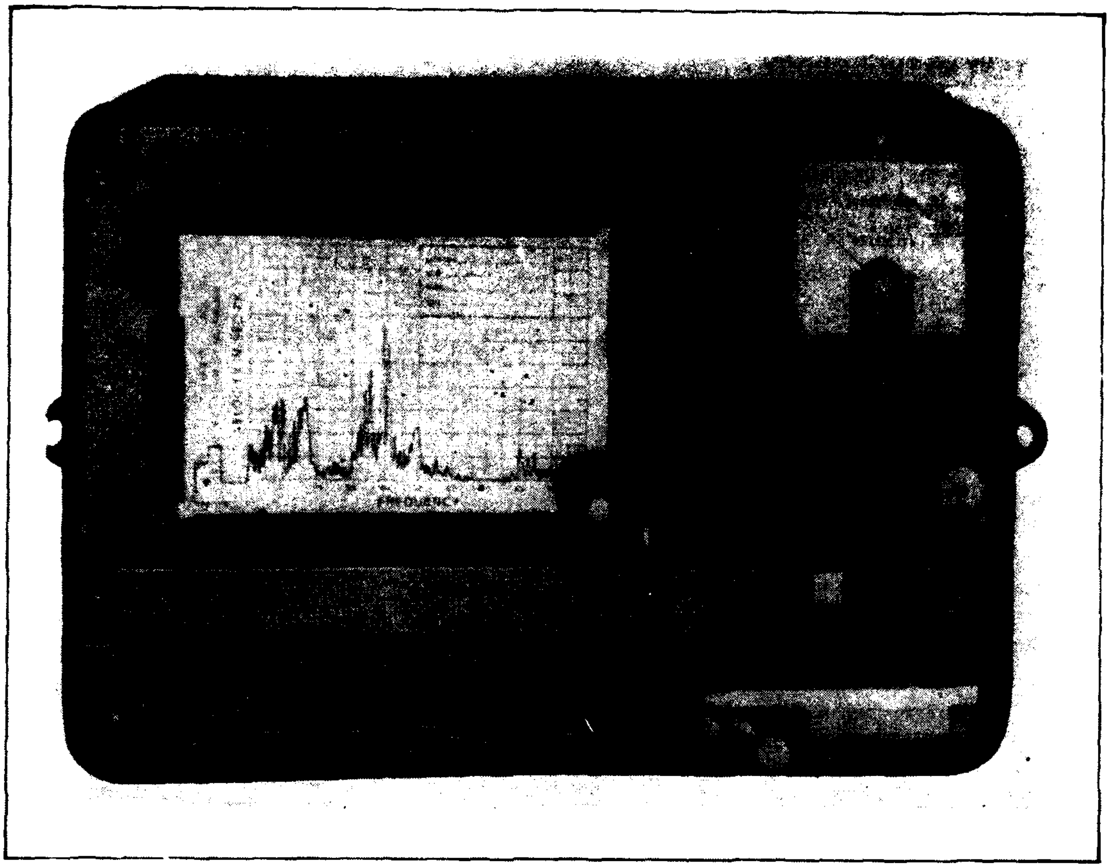


FIGURE 3. MODEL 2538 VIBRATION SIGNATURE RECORDER

TEST METHODOLOGY

11. The aircraft was flown at specified airspeeds and vibration data were recorded during hover and unaccelerated level flight. Test procedures are described in the Results and Discussion section of this report. A detailed list of the test instrumentation is shown in Appendix C, and the data analysis methods are shown in Appendix D.

RESULTS AND DISCUSSION

GENERAL

12. The aircraft was flown in hover and at indicated airspeeds of 50, 80, and 100 knots. The data from various sources were reduced, and plots were made using the harmonic format. The harmonic plots shown in Appendix E are labeled numerically and alphabetically, with lateral and vertical accelerations labeled A and B respectively.

ICE PHOBICS

13. The aircraft was first flown with no ice phobic substance applied to the blades. The data from this flight was used as the baseline (Figures 1A and 1B). Then, a coating of ice phobics was applied, and the aircraft flown under similar conditions (Figures 2A and 2B). The ice phobic was then removed, and a fresh coat applied. The aircraft was hovered in a dusty environment, and then flown in level flight (Figures 3A and 3B). Finally, the ice phobics was again cleaned off, and the aircraft was flown as a baseline for subsequent blade tracking tests (Figure 4A and 4B). Qualitative pilot comments, and quantified pilot comments using the VRS, showed no change during any of the four flights. Examination of the data recorded on the FM data track and processed through the Spectral Dynamics Analyzer showed a slight decrease in vibration level when the ice phobic was applied and flown in a clean environment. The data of the ice phobic in a dusty environment showed characteristics virtually identical to the before and after baseline flights. Examination of the blades subsequent to the flight in the dusty environment showed that the ice phobics had been effectively sand blasted off (Photo A and B). Certain snow or ice particles could produce the same effect which would decrease the protection as a flight continued.

VIBREX

14. The VIBREX is marketed as a maintenance tool rather than as an analytical instrument. One-per-revolution vibration velocity and clock angle are read off the Balancer unit and plotted on charts such as shown in Figures 4 and 5. Vertical vibrations are symptomatic of a faulty track condition, and corrected by change in pitch link length or tab angle. Lateral 1/rev vibrations are normally symptomatic of chordwise or spanwise unbalance and may be corrected by adding or subtracting weights at specific locations, or adjusting the sweep of the blades. The angular orientation and linear scaling of the charts are determined by the mechanical response of the airframe at the accelerometer location, to the rotor. The charts shown have been determined by the manufacturer to be appropriate for the UH-1 model aircraft in general. If precise tracking/balancing information is desired, a specific chart would have to be made for each particular aircraft at only one gross weight, moment of inertia, and accelerometer location. In practice, however, the charts are used to determine the direction of adjustment required, and only approximation of the magnitude of the adjustment. This becomes especially evident when it is understood that to minimize vibration at one airspeed will not necessarily minimize vibration at another airspeed. Therefore, a compromise is normally made whereby vibration is minimized at hover and a typical mission airspeed. Figure 4 shows the fairly typical data scatter with airspeed. The actual pitch link adjustment required for the flight shown in Figure 4 was +1 nut flat of turn.

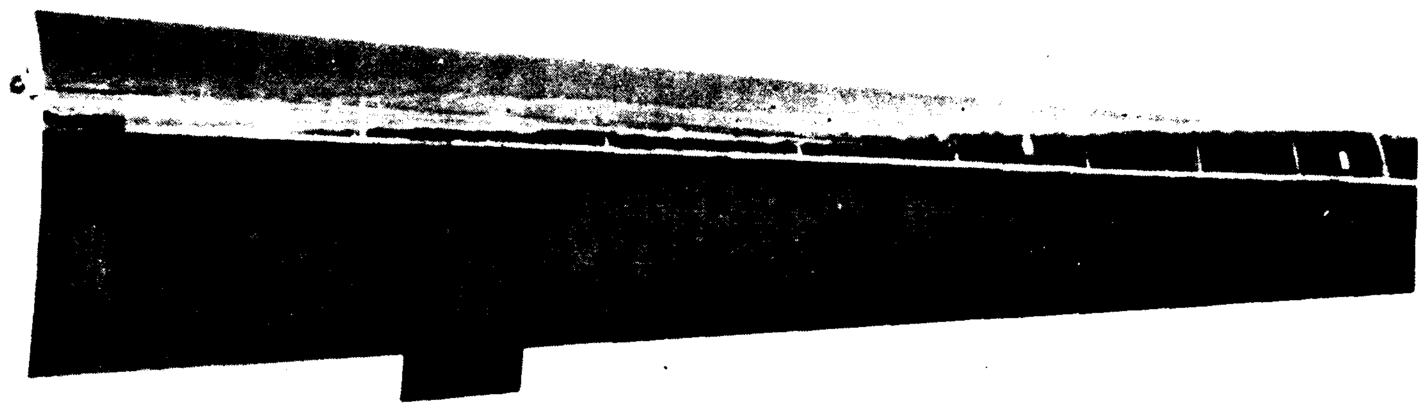


Photo A. Leading Edge Erosion

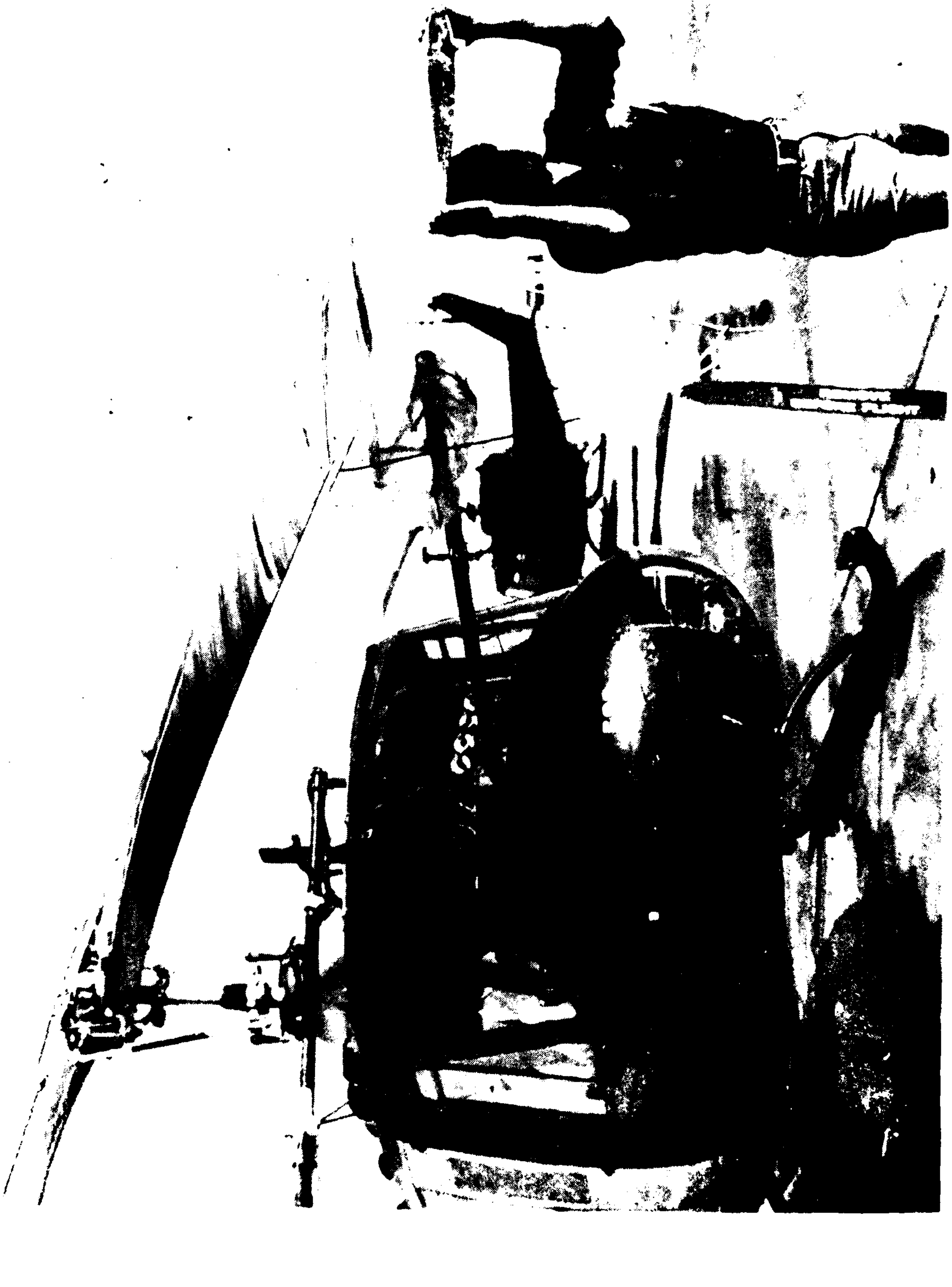


Photo B. Chord-Wise Erosion

NOTES:

1 "BLADE UP" MEANS BLADE SHOULD FLY HIGHER

2 TRACK AFFECTS BALANCE, SO CHECK AND CORRECT BALANCE WHENEVER TRACK IS CHANGED

3 "IPS" IS VERTICAL VIBRATION VELOCITY (CHANNEL B)

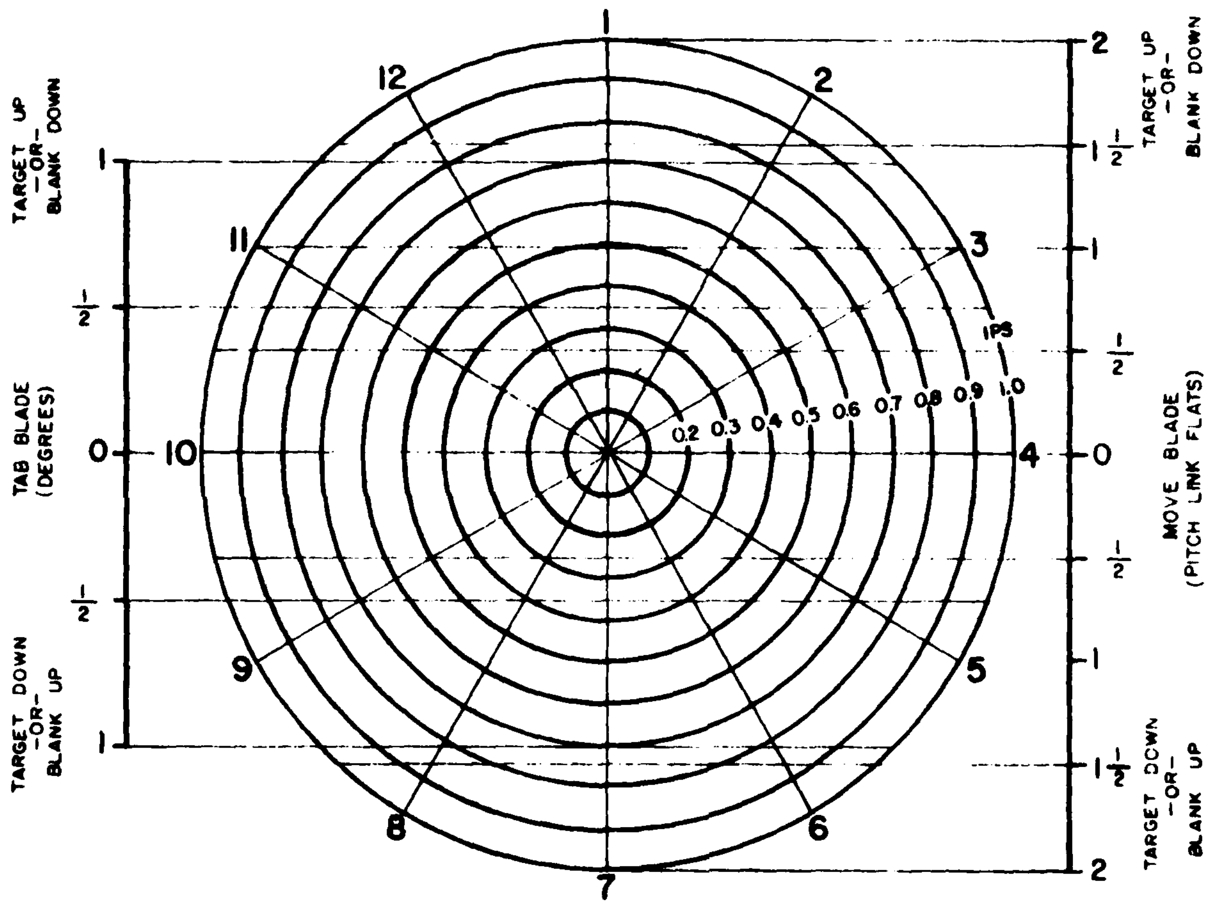


FIGURE 4. TRACK ADJUSTMENT FOR UH-1 HELICOPTER

NOTES:

1 DO NOT ATTEMPT TO BALANCE UNLESS SHIP IS IN GOOD HOVER TRACK

2 THE AMOUNT OF WEIGHT OR SWEEP REQUIRED MAY BE SOMEWHAT DIFFERENT FOR THE VARIOUS MODELS OF UH-1 HELICOPTER

3 "IPS" IS HORIZONTAL VIBRATION VELOCITY (CHANNEL A)

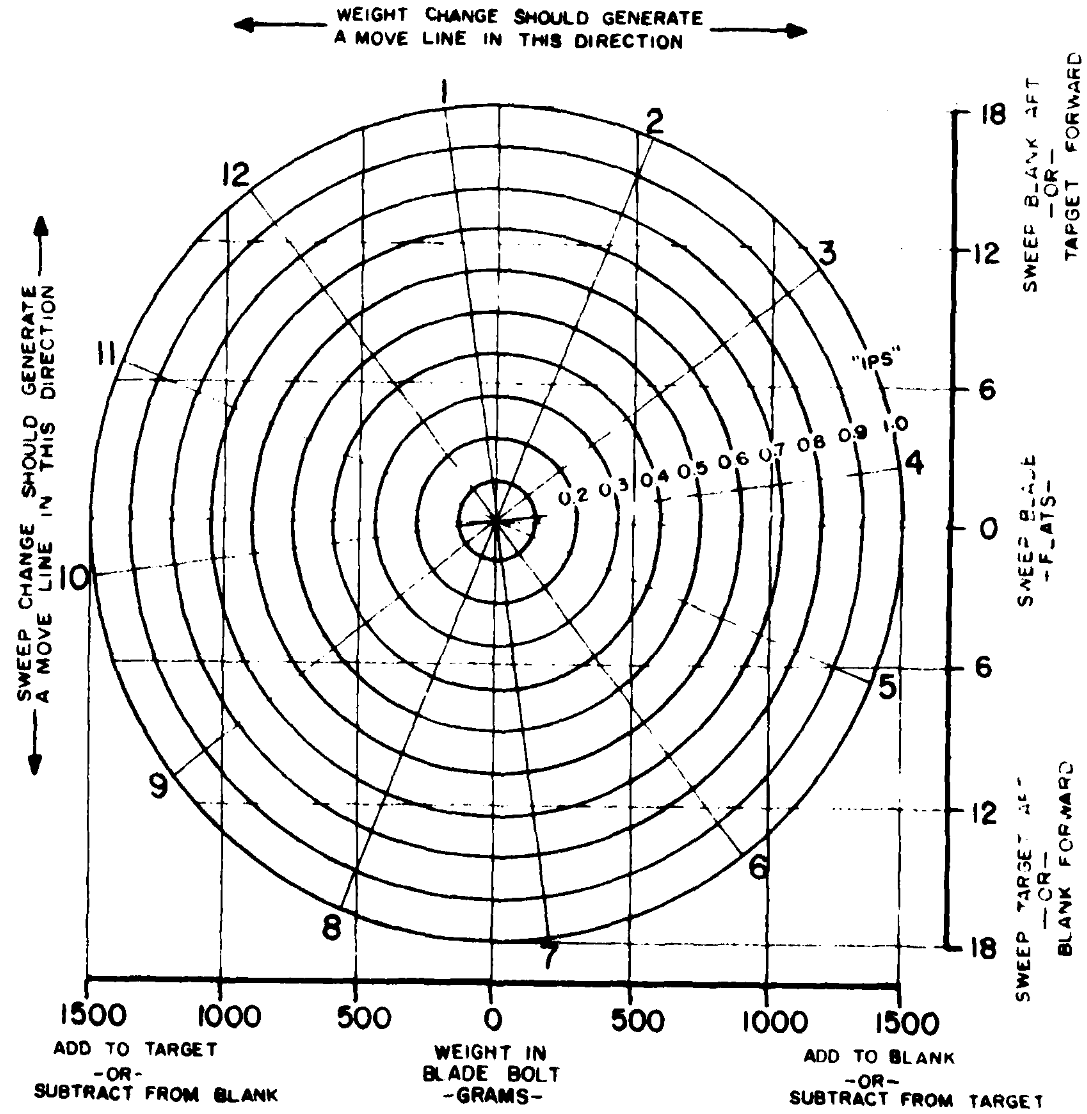


FIGURE 5. BALANCE ADJUSTMENT FOR UH-1 HELICOPTER

15. The VIBREX was evaluated by beginning with the rotor in the best track and balance possible. Then, the blade was brought out of track by changing the pitch links or tabs a specified amount. The aircraft was flown at the four airspeeds, and the VIBREX data was plotted on Figure 4. Since track may be corrected by changing either the tabs or the pitch links, *a priori* knowledge was used in determining the corrections shown in Figure 6. Generally, results from the VIBREX showed excellent agreement with the adjustments actually made.

Figure 6
VIBREX Tracking Data

Figure in Appendix E	VIBREX Indicated Problem	Actual Problem
4	0	0
5	+1 Flats (Pitch)	+1 Flats (Pitch)
6	+2 Flats (Pitch)	+2 Flats (Pitch)
7	-1/2 Flats (Pitch)	-1 Flats (Pitch)
8	-1/2 Flats (Pitch)	-1 Flats (Pitch)
9	0	+3/4 Flats (Pitch)
10	0	0
11	+1/2° (Tab)	+1° (Tab)
12	+1-1/2° (Tab)	+2° (Tab)
13	-1-1/4° (Tab)	-1° (Tab)
14	-1/2° (Tab)	0

16. Because of the data scatter with airspeed, the use of the charts to determine the remedy for an out-of-track/out-of-balance situation is somewhat of an "art". This is made more evident by the fact that changing track affects balance and vice versa. However, the VIBREX, used as a maintenance tool, is a useful aide in correcting of out of track problems. No tests were conducted to specifically examine the ability of the VIBREX to correct out of balance problems. The use of the VIBREX as a vibration measuring device will be discussed later in this section.

SCIENTIFIC-ATLANTA

17. The Scientific-Atlanta VSR, like the VIBREX, is designed primarily as a maintenance tool. It is intended that a history of the aircraft vibration signature be kept, and any noticeable change in signature will cue maintenance personnel to be on the alert for problems in particular areas. The spectral signature (vibration velocity versus frequency), is plotted on a preprinted 4 by 6 inch file card (Figure 7). Various color pens are available, so that lateral and vertical vibrations may be plotted on a single card.

18. The VSR is an almost ideal instrument to record "quick look" test data. It is highly portable, can be operated by unskilled personnel, and the format of the output is what is normally required for analysis. A comparison of the VSR data (shown in Figure 10A through 11B, Appendix E) with other methods is presented later in this section.

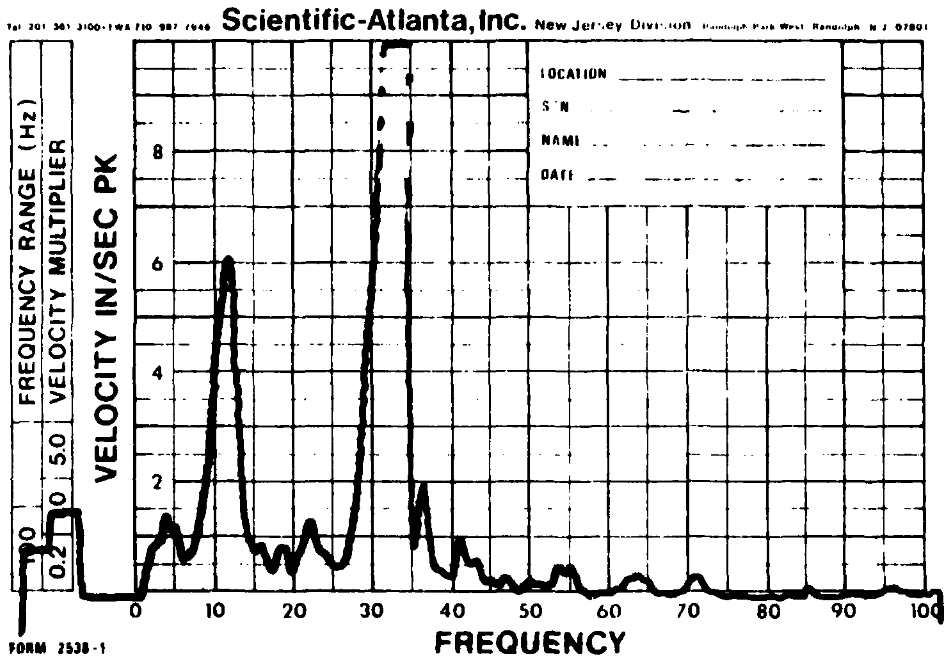


FIGURE 7. SAMPLE VRS OUTPUT

PILOT COMMENTS VERSUS DATA

19. During the flights, four test pilots were requested to evaluate the vibration level in accordance with the VRS shown in Figure 8. Preliminary plots were made of the VSR versus the vibration amplitudes obtained by the Spectral Dynamics analyzer. No meaningful correlation could be found. The sensors for the instrument measured vibrations were located near the aircraft center of gravity: more than 7½ feet from the seats. It was concluded that the dynamic response of the aircraft structure is such that vibration measurements at the center of gravity are not representative of vibrations at the front seats. The correlation of vibration data with the VRS is still a subject of interest, and it is recommended that such a study be undertaken by USAAEFA in a properly instrumented aircraft.

COMPARISON OF VIBRATION ANALYSIS METHODS

20. Within the past decades, vibration analysis at USAAEFA has been accomplished through the use of a hardware spectral analyzer (Spectral Dynamics Model SD301C with a Model SD302B ensemble averager) or the FM data track (Appendix D). The output of the analyzer is a spectral plot showing either level (dB) or amplitude (g) versus frequency (Figure 9). For convenience, amplitude is normally requested; however, level was requested for this test because of the increased resolution possible with that scale. The level from the spectral plot must be manually converted to peak acceleration (g) for the frequencies of interest.

21. The accelerometers used on the FM track were also recorded on PCM (through a 20 Hz filter). Time history plots of random points were made from the PCM data (Figure 10) and were used to corroborate the 2/rev FM results. The two methods yielded virtually identical results in all cases checked.

22. It was originally intended that the PCM data be computer-processed using a FFT program recently written at USAAEFA. However, errors in the program were discovered, and time constraints precluded the possibility of waiting for the program to be corrected. Because most of the test data processed at USAAEFA is on PCM, it is apparent that computing vibration parameters using digital methods from the PCM track would offer many advantages. Most important, vibration data would be taken at precisely the same time as other data, and any manipulation of the data could be handled easily in the computer. It is intended that work on the digital methods be continued and that it will be used in first preference if accuracy proves to be comparable to that of the spectral analyzer.

23. Using the VIBREX as a vibration measuring instrument, it is necessary to "dial in" the frequency of interest, and record the magnitude shown on the meter. Although this is time consuming and awkward, it was done during this evaluation, and the results shown in Figures 1A through 14B in Appendix E. One per rev vibrations were so low that no meaningful comparison can be made of the data. The vertical results of the VIBREX show a bias of approximately +0.1G on 2/rev and +0.05G on 4/rev compared to the spectral analyzer. The lateral results showed good agreement with the analyzer. The trends shown by the VIBREX data on both axes closely resembled the trends of the analyzer data.

DEGREE OF VIBRATION	DESCRIPTION[1]	PILOT RATING
No vibration		0
Slight	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1 2 3
Moderate	Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period.	4 5 6
Severe	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can only be done with difficulty.	7 8 9
Intolerable	Sole preoccupation of aircrew is to reduce vibration level.	10

[1] Based upon the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

FIGURE 8. VIBRATION RATING SCALE

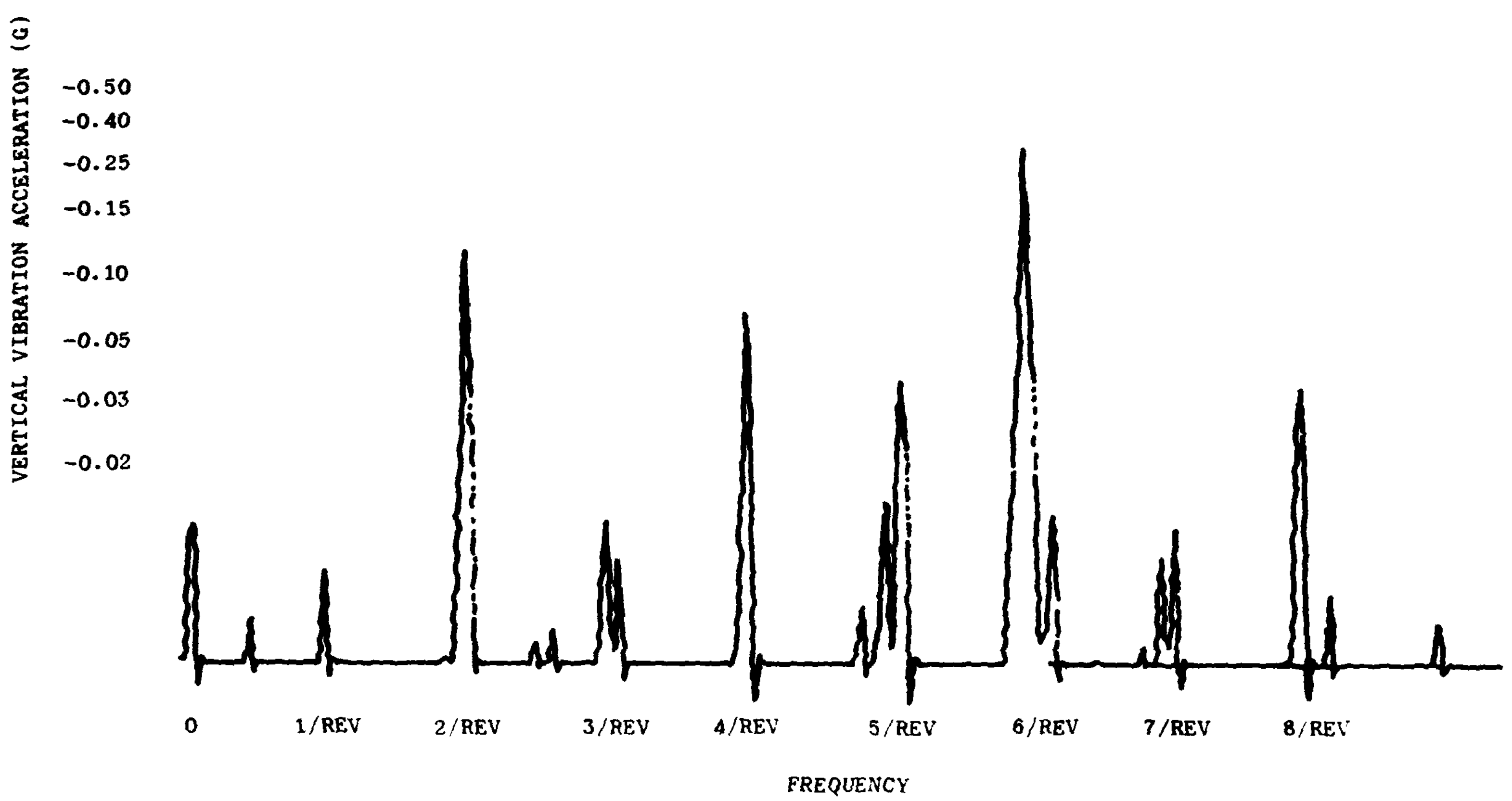


FIGURE 9. SAMPLE SPECTRAL ANALYZER PLOT

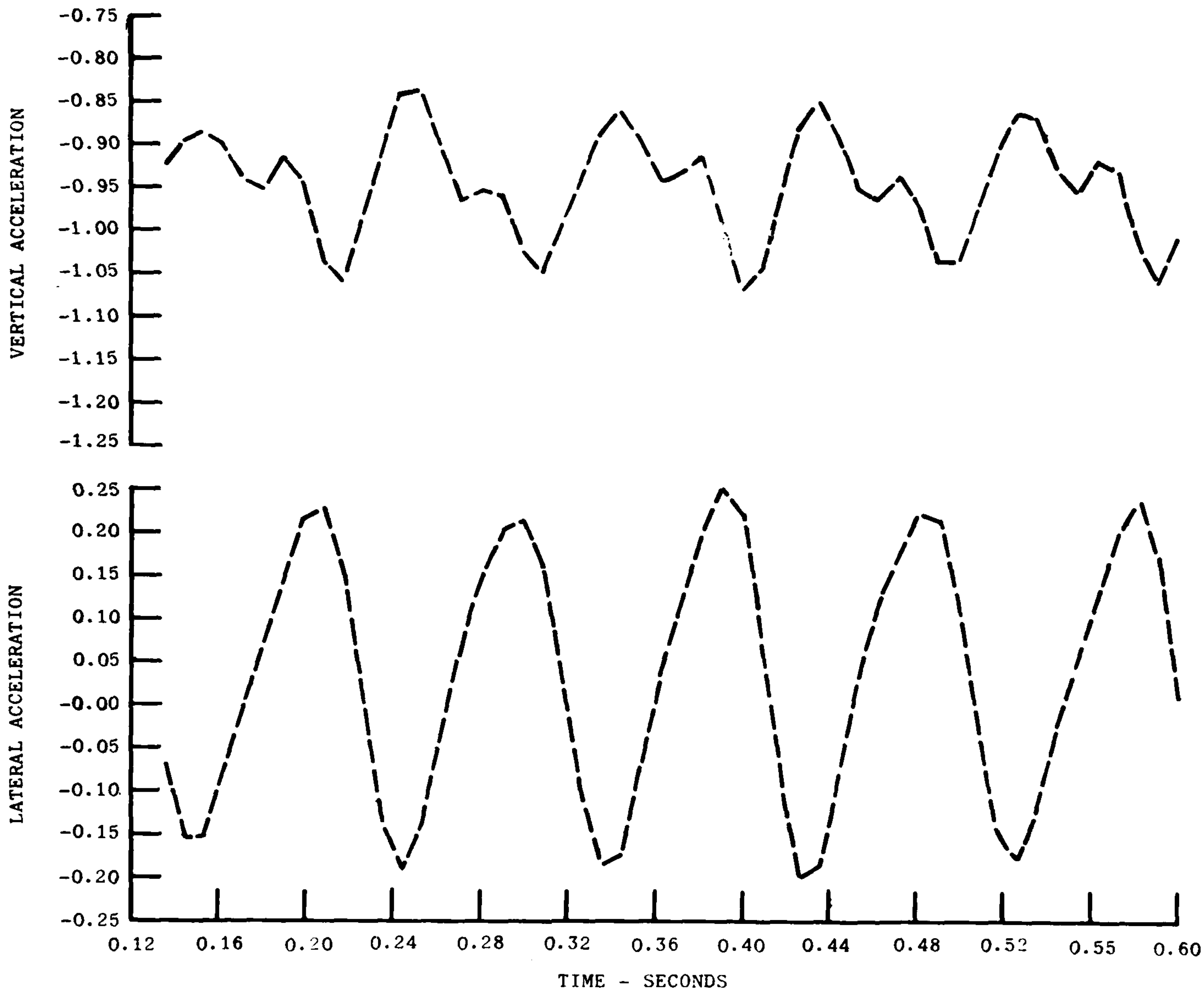


FIGURE 10. SAMPLE OF PCM ACCELERATION DATA

24. The Scientific-Atlanta VSR was used on only two flights (Figure 10A through 11B, Appendix E). Despite some scatter at 6/rev, the data compare well with the spectral analyzer in both axes. Also, the ease with which the VSR can be used in a test environment makes it a valuable "quick look" instrumentation device.

CONCLUSIONS

25. The Dow Corning E2460-40-1 (redesignated E2978-46) ice phobic coating has no adverse effects on helicopter vibration (para 13).

26. The Chadwick-Helmuth VIBREX accurately determined corrections to be made to correct out of track conditions (para 15).

27. A digital technique for vibration analysis using PCM data would be a significant advantage over current methods (para 23).

28. The VIBREX is difficult to use as a vibration measuring instrument unless the frequencies of interest are already known (para 23).

29. The trends shown by VIBREX data closely resembled the trends of the data from the spectral analyzer (para 23).

30. The Scientific-Atlanta Vibration Signature Recorder gave results which closely compared to data from the spectral analyzer (para 24).

31. The Scientific-Atlanta VSR is very easy to use (para 24).

APPENDIX A. REFERENCES

1. Final Report, USAAEFA, Project No. 77-30, *Artificial Icing Test, Ice Phobic Coatings on UH-1H Helicopter Rotor Blades*, June 1978.

2. Technical Manual, TM 55-1520-210-10, *Operators Manual, Army Model UH-1D/H Helicopters*, 25 August 1971, with Change 18.

3. Preliminary Technical Manual, TM 55-4920-402-13&P, *Operating Instructions, Aviation Unit and Aviation Intermediate Maintenance Manual, VIBREX Balancing Kit*, 15 March 1978.

4. Manual, Scientific-Atlanta, Inc., *Model 2538 Vibration Signature Recorder, Instruction Manual.*

5. Training Course and Application Notes, Spectral Dynamics Corp., *Theory, Troubleshooting, and Calibration of Real Time Analyzer Instruments*, March 1972.

APPENDIX B. DESCRIPTION

VIBREX

1. The VIBREX Balancing Kit (hereafter referred to as VIBREX) is used to measure and indicate the level of vibrations induced by the main rotor and tail rotor of a helicopter. The VIBREX analyzes the vibration induced by out-of-track, or out-of-balance rotors, and then by plotting vibration amplitude and clock angle on a chart, the amount and location of rotor track or weight changes is determined. In addition, the VIBREX is used in troubleshooting by measuring the revolutions-per-minute (RPM) or frequency of unknown disturbances.

2. The VIBREX is housed in a Carrying Case and consists of the components listed in Table B-1. The main units of the VIBREX are Balancer/Phazor 177M6A, Strobex Tracker 135M11, and VIBREX Tester 11. The primary airframe mounted components are three Accelerometers 4177B and two Magnetic Pickups 3030AN.

a. Balancer/Phazor 177M6A. The key feature of the Balancer/Phazor (hereafter referred to as Balancer) is a tuneable, electronic bandpass filter which is tuned to reject all but one frequency, or vibration under study. The meter reads the level of vibration at the rate (RPM) of concern, which is indicative of the amount of the required change (track or balance). The Phazor section contains a phase meter that reads clock angle, or phase angle, between a one-per-revolution Magnetic Pickup azimuth signal from the rotor and a vibration signal from the Accelerometer.

b. Strobex Tracker 135M11. The Strobex Tracker (hereafter referred to as Strobex) is a small hand held lightweight combination power supply and strobe flash tube. It illuminates reflective targets on the tail rotor to measure tail rotor clock angle, and on the main rotor to indicate rotor track and lead-lag.

c. VIBREX Tester 11. The VIBREX Tester (hereafter referred to as Tester) provides accurate calibration and complete functional check of the VIBREX. The Tester shakes (vibrates) the Accelerometer to measure vibration amplitude in inches-per-second (IPS) and rate (RPM) functions of the balancer. Phase or clock angle functions of the Phazor section are verified by a rotating interrupter plate and the Magnetic Pickup to provide double and single interrupter logic singals. The RPM dial of the Strobex is accurately checked against the known rotor speed of the Tester motor.

d. Accessories Following is a list of accessories that are used with the Balancer, Strobex, and Tester:

(1) Magnetic Pickups and Interrupter Sets. Pickup device to provide magnetic impulses from rotor to Balancer. Magnetic pickups are located on rotating platforms while Interrupter Sets are located on stationary platforms.

(2) Accelerometers. Provides the Balancer with an electrical representation of the physical motion of the point to which it is attached.

(3) Reflective and Tip Target Sets. Reflects Strobex flash pulses back to Strobex operator.

(4) Balance and Tracking Charts. Used to calculate weight, sweep, pitch link, tab, etc., to correct rotor problems.

Table B-1 VIBREX Balancing Kit Components

Quantity	Nomenclature	Model Number
1	Balancer/Phazor	177M6A
1	Strobex Tracker	135M11
1	VIBREX Tester	11
1	Signal Simulator	B4305
1	Gram Scale	47
1	Carrying Case	34B
1	Flash Tube (Spare)	35S
1	DC Extension Cable	A3529
2	Magnetic Pickup	3030AN
2	Magnetic Pickup Cable	A3319-2
3	Accelerometer	4177B
1	Accelerometer Cable	A4296-2
2	Accelerometer Cable	A4296-1
1	Corrector Chart	3597
1	DC Adapter Cable	B3140-1
1	DC Adapter Cable	B3140-5
1	DC Adapter Cable	B3140-9
1	Cable Ties Package	4208
1	Serial Number/Warranty Label	AW4756
1	Magnetic Pickup Bracket	A3104
1	Magnetic Pickup Bracket	C4758
1	Magnetic Pickup Bracket	C4559
1	Magnetic Pickup Bracket	B3159
1	Accelerometer Bracket	A3383
1	Accelerometer Bracket	A3382
1	Interrupter Set	B3103
1	Interrupter Set	B3251
1	Interrupter Set	B3380
1	Tip Target Set	A3387
1	Reflective Target Set	A3300
1	M/R Track and Balance Chart	4262
1	M/R Track and Balance Chart	4273
1	M/R and T/R Checklist	4300
1	T/R Track and Balance Chart	3413
1	T/R Track and Balance Chart	4020
1	T/R Track and Balance Chart	4173
1	T/R Track and Balance Chart	3467
1	M/R Balance Chart	3411
1	T/R Balance Chart	3438
1	Tracking Chart	3875
1	Balance Chart	4210
1	Checklist	4280
1	Checklist	4290
1	Tip Target	A3428-2
1	Backup Bar (used with B3159)	A3160

(5) Signal Simulator. Provides signal simulation for troubleshooting the Balancer and Strobex.

(6) Gram Scale. Provides accurate weight measurement for weights to be installed on rotors.

(7) Carrying Case. Provides a compact and secure method of transporting the VIBREX. Also provides convenient storage for VIBREX components.

(8) Cables. Applies power to and interfaces VIBREX with airframe mounted components.

(9) Brackets. Airframe mounting devices for Accelerometers and Magnetic Pickup.

(10) Checklists. Provides installation and operating procedures for individual aircraft installations.

3. Figure B-1 shows a typical VIBREX installation. On the installation tested, the vertical accelerometer was mounted on the front instrument panel, and the lateral accelerometer was mounted on the aft bulkhead forward of the transmission.

SCIENTIFIC-ATLANTIC VIBRATION SIGNATURE RECORDER

4. The STROBEX is used to view the tip path, and the Balancer is used to indicate vibration velocity. A particular frequency of interest is set on the dial of the Balancer, and the corresponding velocity is read on the meter. This procedure may be repeated for any frequency.

5. The Model 2538 is intended as a preventive maintenance tool enabling the vibration characteristics of machinery to be periodically monitored. The Model 2538 provides a permanent record of these vibration characteristics enabling plant and maintenance engineers to analyze vibration trends in order to predict faults and take corrective action. The Model 2538 was designed to be truly portable, reliable, and extremely simple to implement and operate by non-technical personnel. It is a portable rechargeable battery operated spectrum analyzer with a built in X-Y recorder which plots the vibration velocity against frequency on standard 4" x 6" (10 cm x 15 cm) preprinted file cards.

6. Specifications:

a. Electrical:

(1) Velocity Range: Two position toggle switch selects either 1/5 or 0.2/1 in/sec peak full scale (F. S.) sensitivity (when used with an accelerometer having 10mV/g sensitivity). Actual sensitivity in each switch position will be determined automatically.

(2) Velocity Amplitude Accuracy: ±5% F. S. (excluding accelerometer)

(3) Crest Factor. 6 dB minimum at F. S.

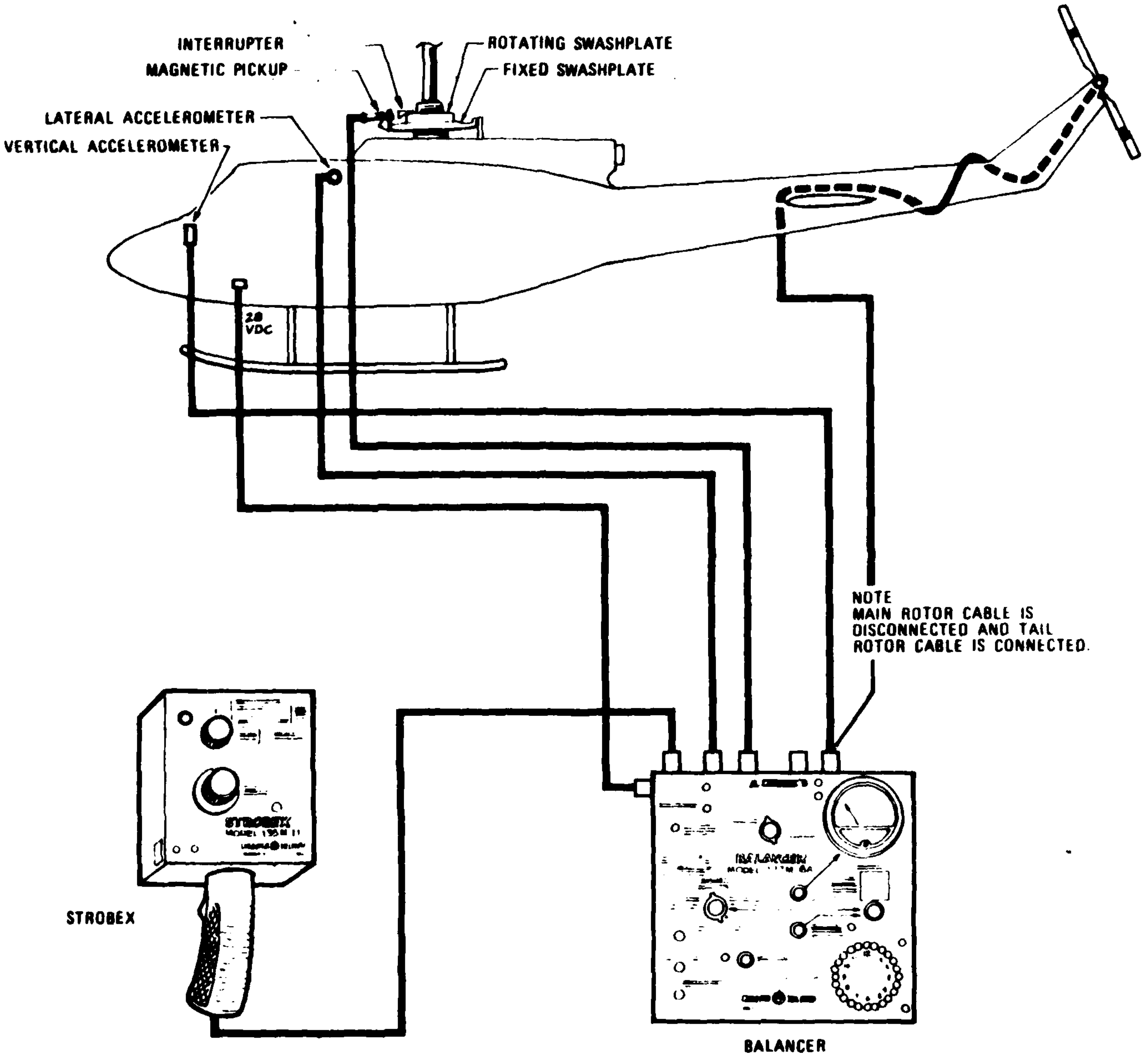


FIGURE B-1. TYPICAL VIBREX TO AIRFRAME INTERFACE

(4) Frequency Range. Front panel selection of either 0 to 100 Hz or 0 to 1500 Hz.

(5) Frequency Accuracy. ±5% F. S.

(6) Filter Bandwidth. Three pole synchronously tuned bandpass filter. Bandpass is 2.2 Hz in 100 Hz range and 15 Hz in 1500 Hz range.

(7) Filter Bandwidth Accuracy. ±5%.

(8) Frequency Response.

100 Hz Range:	±2% from 5 Hz to 100 Hz 3 dB down at 2.5 Hz and 140 Hz
1500 Hz Range:	±2% from 5 Hz to 1500 Hz 3 dB down at 2.5 Hz and 2100 Hz
Roll Off Below 5 Hz	18 dB/Octave
Roll Off Above Upper 3 dB Frequency:	18 dB/Octave

(9) Velocity Meter. Two scales, 0 to 1 in/sec and 0 to 5 in/sec peak.

(10) Broadband. Continuous broadband capability controlled by a toggle switch and indicated by a LED.

(11) Recording Time. 60 ±6 seconds.

(12) Battery Life. 100 recordings (minimum) between recharges.

(13) Battery Charger. Built in battery charger for 115/230 VAC, 50/60 Hz operation at 2 VA.

(14) Recharge Time. 14 to 16 hours.

(15) Operating Temperature. 0° to 50°C.

(16) Recommended Storage Temperature. +25°C.

b. Mechanical:

(1) Overall Dimensions. 10-1/4"D x 14-1/4"W x 10"H (26cm D x 36.2cm W x 25.4cm H).

(2) Weight. 18 lbs (8.2 kg).

7. The Model 2538 is supplied with the following:

Item	Quantity	Description	Part No.
1	1	Accelerometer	9952
2	1	10' Accelerometer Interconnecting Cable	9194
3	1	Accelerometer Magnetic Clamp Assembly	9195-1
4	1	Carry Strap	9490
5	200	Card, Velocity (in/sec) vs. Frequency (0 - 100 Hz)	2538-1
6	200	Card, Velocity (in/sec) vs. Frequency (0-1500 Hz)	2538-2
7	2	Disposable Pens (Red)	82-17 (Red)
8	2	Disposable Pens (Green)	82-17 (Green)
9	2	Disposable Pens (Black)	82-17 (Black)
10	2	Disposable Pens (Blue)	82-17 (Blue)
11	12	Rechargeable NiCad 1.2 V "C" cell batteries (Installed)	CH 35 or equivalent

APPENDIX C. INSTRUMENTATION

1. The test aircraft, JUH-1H, serial number 69-15532, is designated as a special test aircraft and has a magnetic tape instrumentation system semi-permanently installed. Accelerations in 3 axes at the aft bulkhead in front of the transmission are recorded on the FM data track. The same accelerometers are also recorded on PCM. Other parameters recorded on PCM include:

   a. Time of day
   b. Record number
   c. Event flag
   d. Outside air temperature
   e. Fuel used
   f. Pressure altitude
   g. Airspeed
   h. Main rotor speed

2. Hand recorded parameters were as follows:

   a. Record number
   b. Airspeed
   c. Main rotor speed
   d. Rate of climb
   e. Outside air temperature
   f. Pressure altitude
   g. Track picture
   h. VIBREX
      (1) Clock angle
      (2) Vibration velocity
   i. Pilot rating

3. Additionally, on two flights, the Scientific-Atlantic Vibration Signature Recorder was used to produce spectral signatures in the lateral and vertical axes.

APPENDIX D. DATA ANALYSIS METHODS

GENERAL

1. The VIBREX and the Scientific-Atlanta Vibration Signature Recorder are described in Appendix B. The Spectral Dynamic 301 real time spectral analyzer is described in Reference 5, Appendix A.

SPECTRAL ANALYZER

2. The spectral analysis performed by the Model 301 analyzer and 302 ensemble averager converted the data from the time domain (acceleration as a function of time) to frequency domain (acceleration as a function of frequency). The output is a digital plot of acceleration level (dB) versus frequency (Hz) produced on a Hewlett-Packard X-Y plotter. The data were analyzed over a 50 Hz range with a band width of 0.15 Hz. Four ensembles were taken of 10 seconds duration each. The analyzer was set up to produce a reading of zero dB at a full scale RMS input and an attenuater setting of 30 dB plus some offset. Amplitudes were computed using the following equation:

$$A = \sqrt{2}\, A_{FS}\, 10^{(X + O - 30)/20}$$

Where:

A = Peak amplitude (g)
A_{FS} = Full scale RMS, Lateral: 4.79 g, Vertical: 3.61 g
X = Reading (dB)
O = Offset, Lateral: 10 dB, Vertical: 20 dB

VIBREX AND VSR

3. Both the VIBREX and the Scientific-Altanta VSR Systems output peak vibration in inches per second (IPS). A sinusoidal displacement may be described by the equation:

$$s = A \sin(\omega t)$$

Where:

s = Displacement
A = Peak amplitude
ω = Frequency (radians/second)
t = Time

differentiating once,

$$v = \frac{ds}{dt} = A\omega \cos(\omega t)$$

Where:

v = Velocity

differentiating again,

$$a = \frac{dv}{dt} = -A\omega^2 \sin(\omega t)$$

Where:

a = Acceleration

disregarding phase,

$$a = v\omega$$

Since desireable units are gs, IPS, and RPM respectively, the equation with units conversion is:

$$a = 0.0002713\ v\omega$$

APPENDIX E. TEST DATA

INDEX

FIGURE 1A

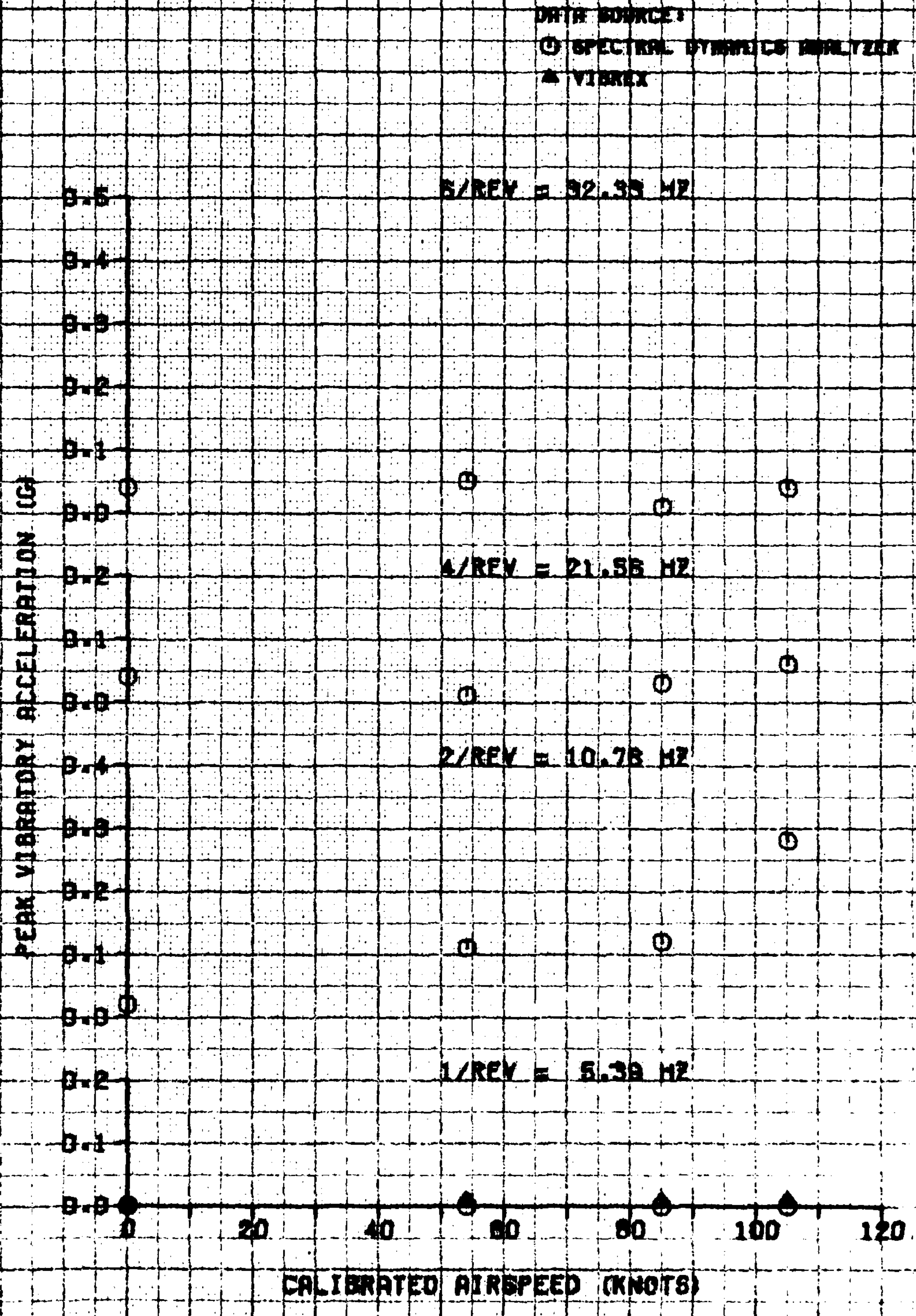
VIBRATION CHARACTERISTICS

ICE PHOBICS TEST BASELINE

CG LATERAL ACCELERATION

JUH-1H USA S/N 69-15532

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALT (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)
8020.	138.8 (MID)	-.5 (LT)	4720.	7.0	323.



FLT 48A LAT

FIGURE 18

VIBRATION CHARACTERISTICS

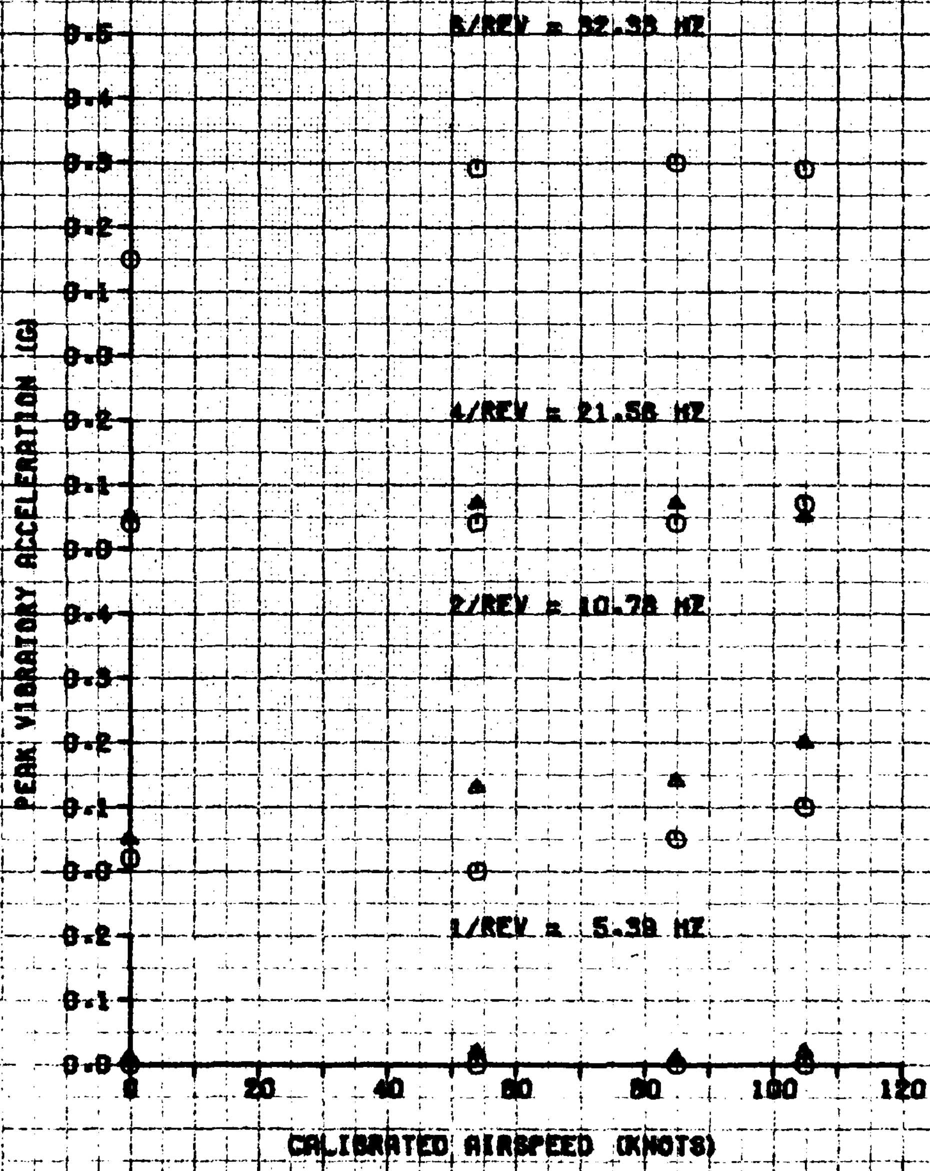
ICE PHOBICS TEST BASELINE

CG VERTICAL ACCELERATION

JUH-1H USA S/N 68-15532

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALT (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)
9020.	130.8 (MID)	-.5 (LT)	4720.	7.0	323.

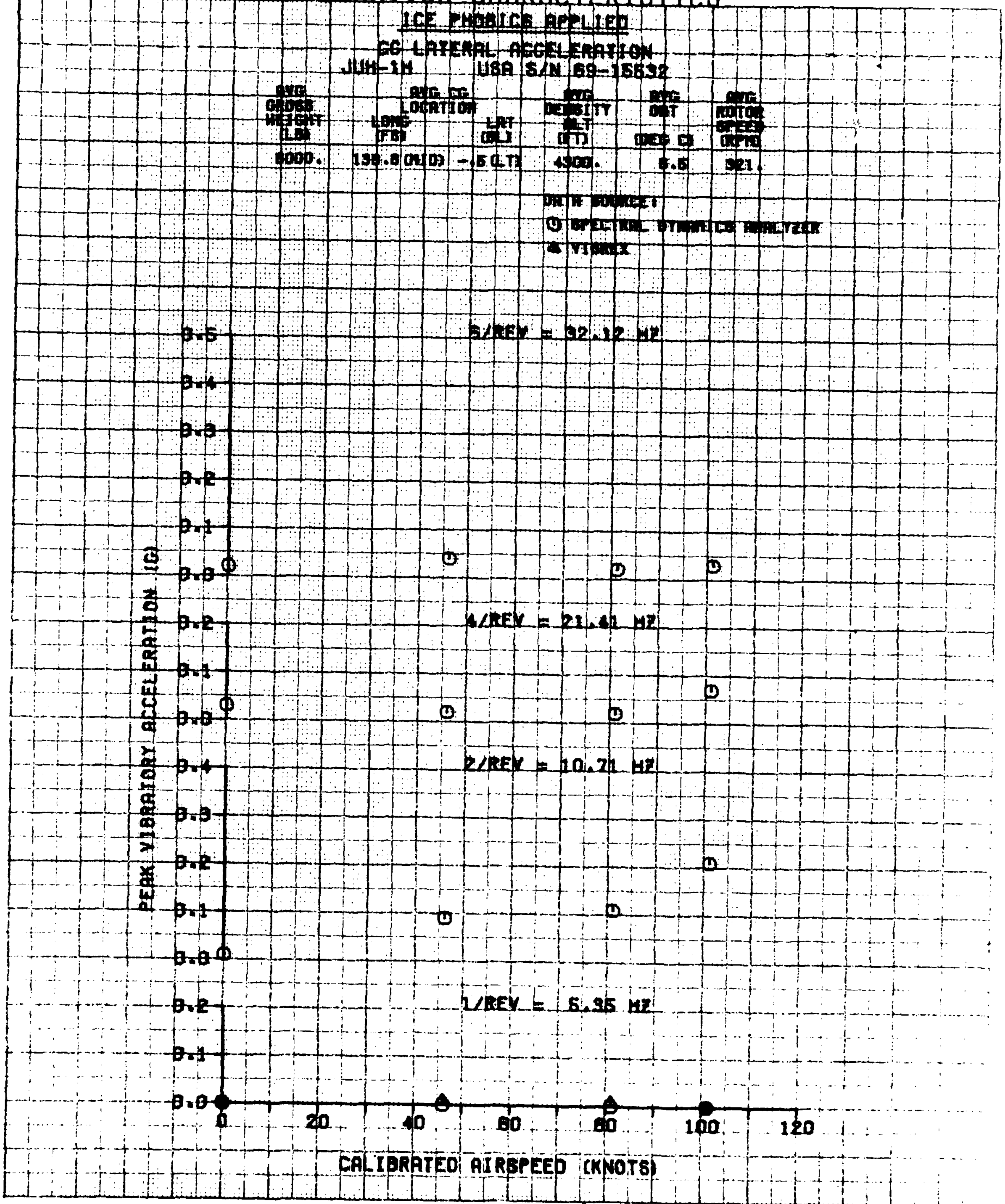
DATA SOURCE:
Ⓞ SPECTRAL DYNAMICS ANALYZER
▲ VIBREX



FLT 40A VERT

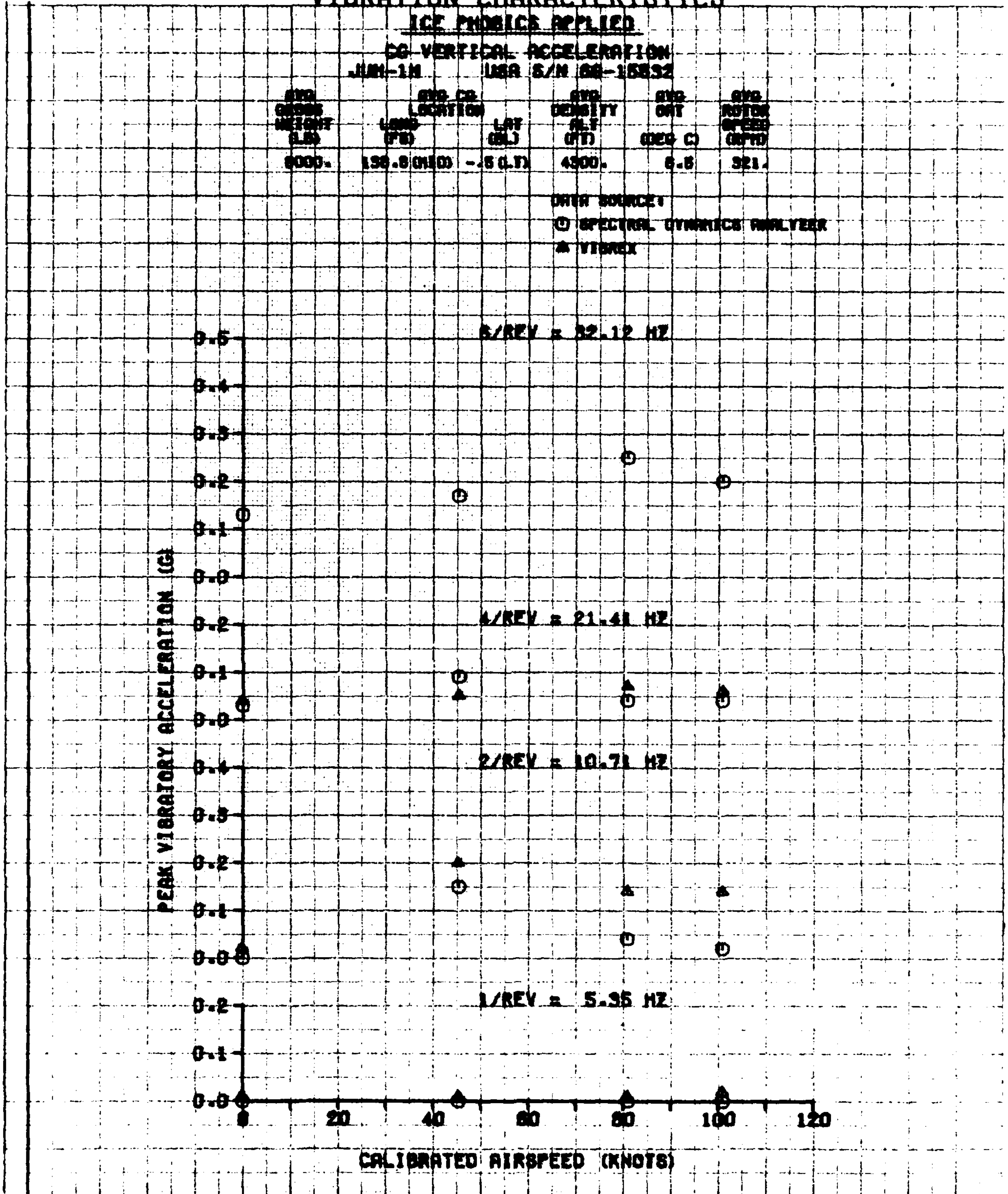
FIGURE 2A

VIBRATION CHARACTERISTICS



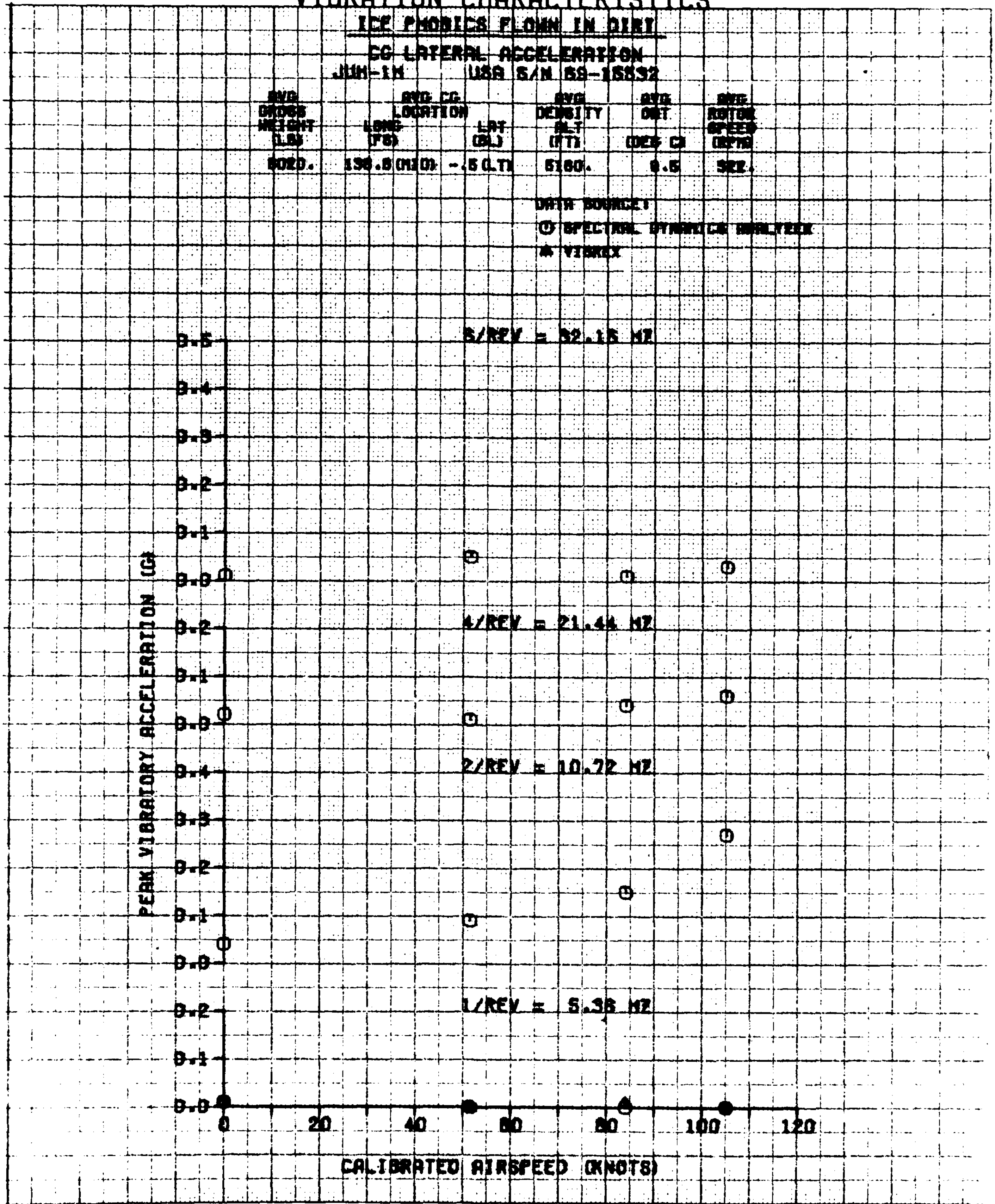
FLT 47 LAT

FIGURE 28
VIBRATION CHARACTERISTICS



FLT 47 VERT

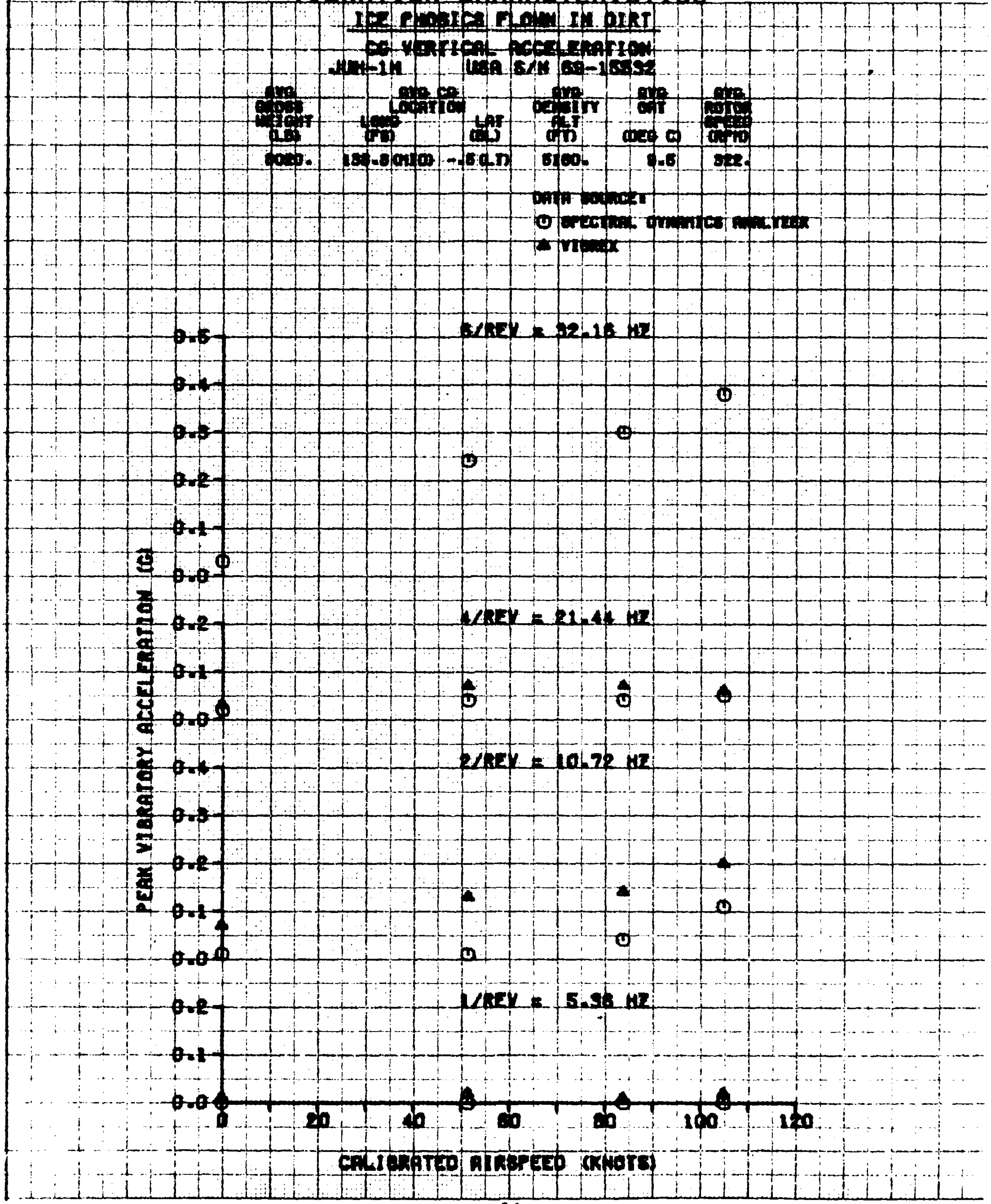
FIGURE 3A
VIBRATION CHARACTERISTICS



FLT 488 LAT

FIGURE 38

VIBRATION CHARACTERISTICS



FLT 408 VERT

FIGURE 4A

VIBRATION CHARACTERISTICS

BLADE TRACKING TEST BASELINE

CG LATERAL ACCELERATION

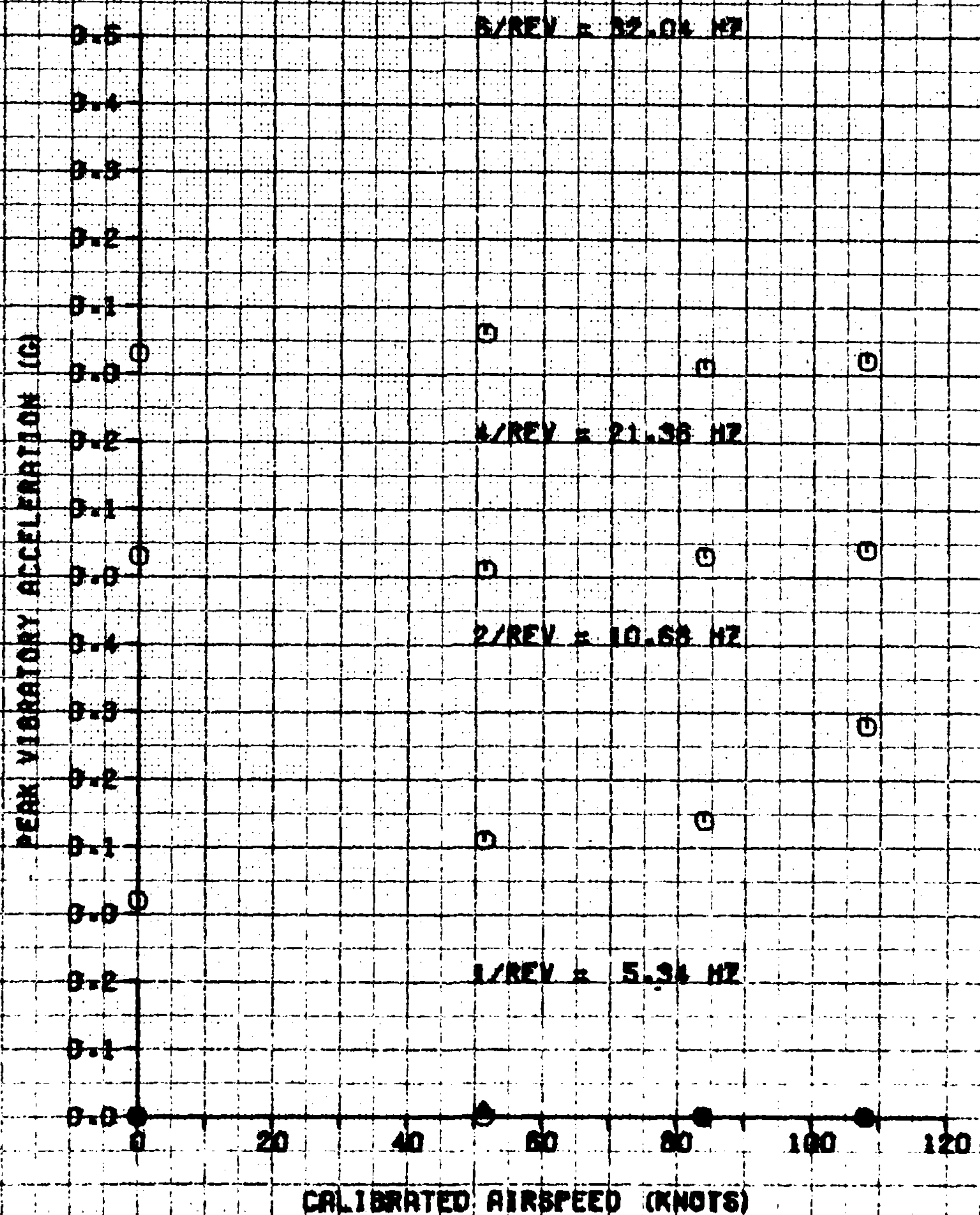
JUH-1H USA S/N 69-15532

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALT (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)
8010.	138.8(MID)	-.6(LT)	6000.	9.0	320.

DATA SOURCE:

⊙ SPECTRAL DYNAMICS ANALYZER

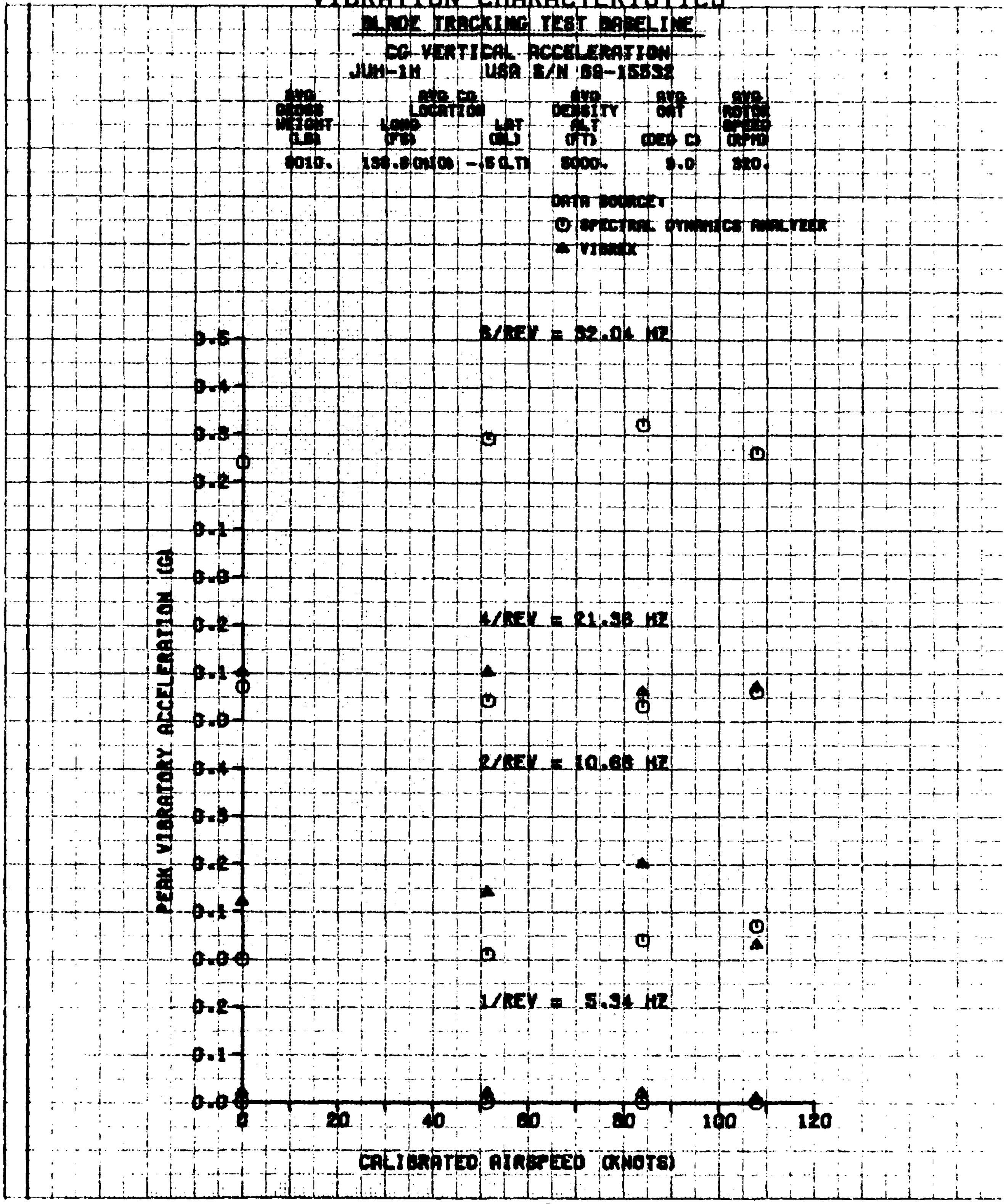
▲ VIBREX



FLT 49 LAT

FIGURE 48

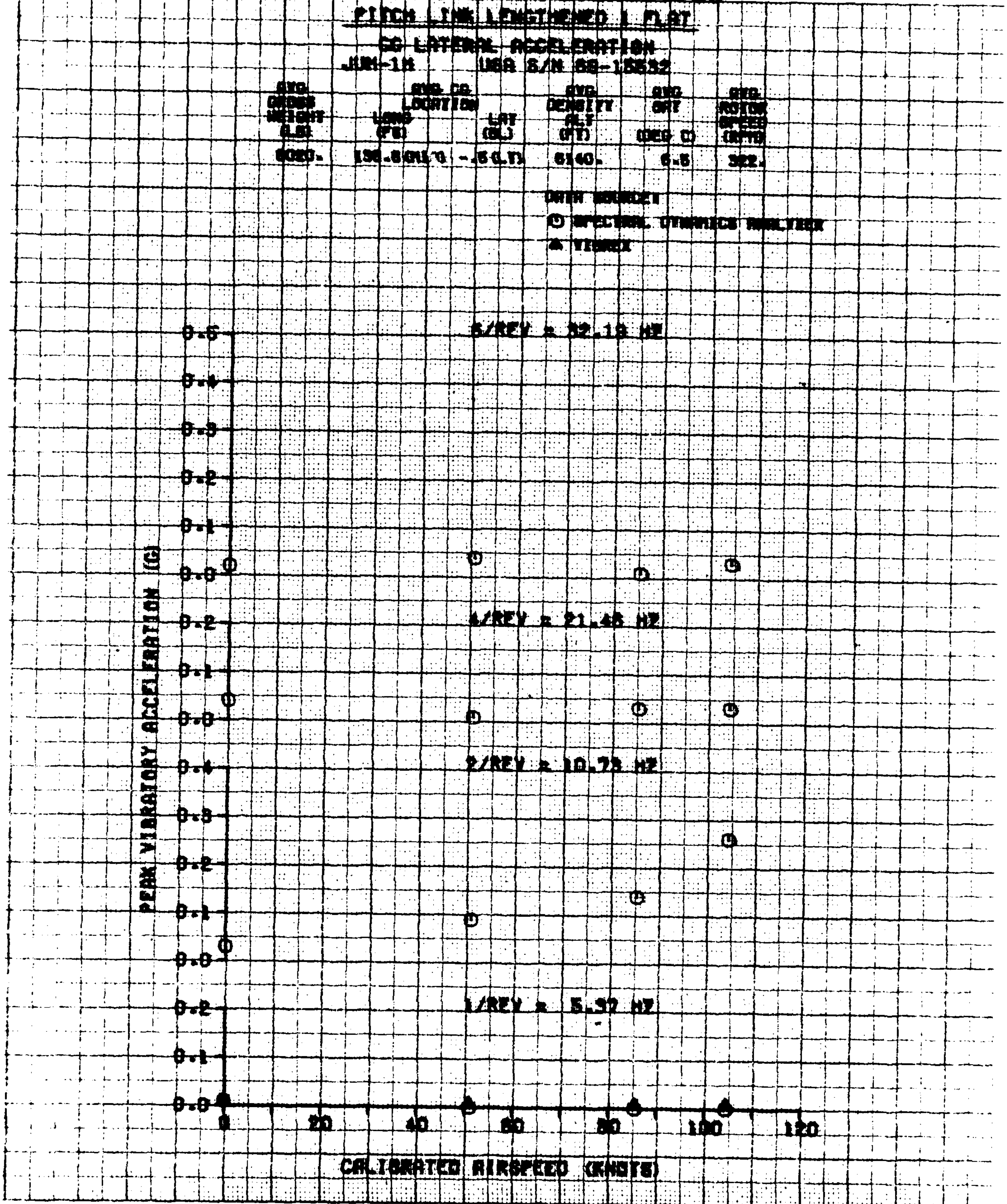
VIBRATION CHARACTERISTICS



FLT 48 VERT

FIGURE 5A

VIBRATION CHARACTERISTICS



FLT 51 LAT

FIGURE 5B

VIBRATION CHARACTERISTICS

PITCH LINK LENGTHENED 1 FLAT

CG VERTICAL ACCELERATION

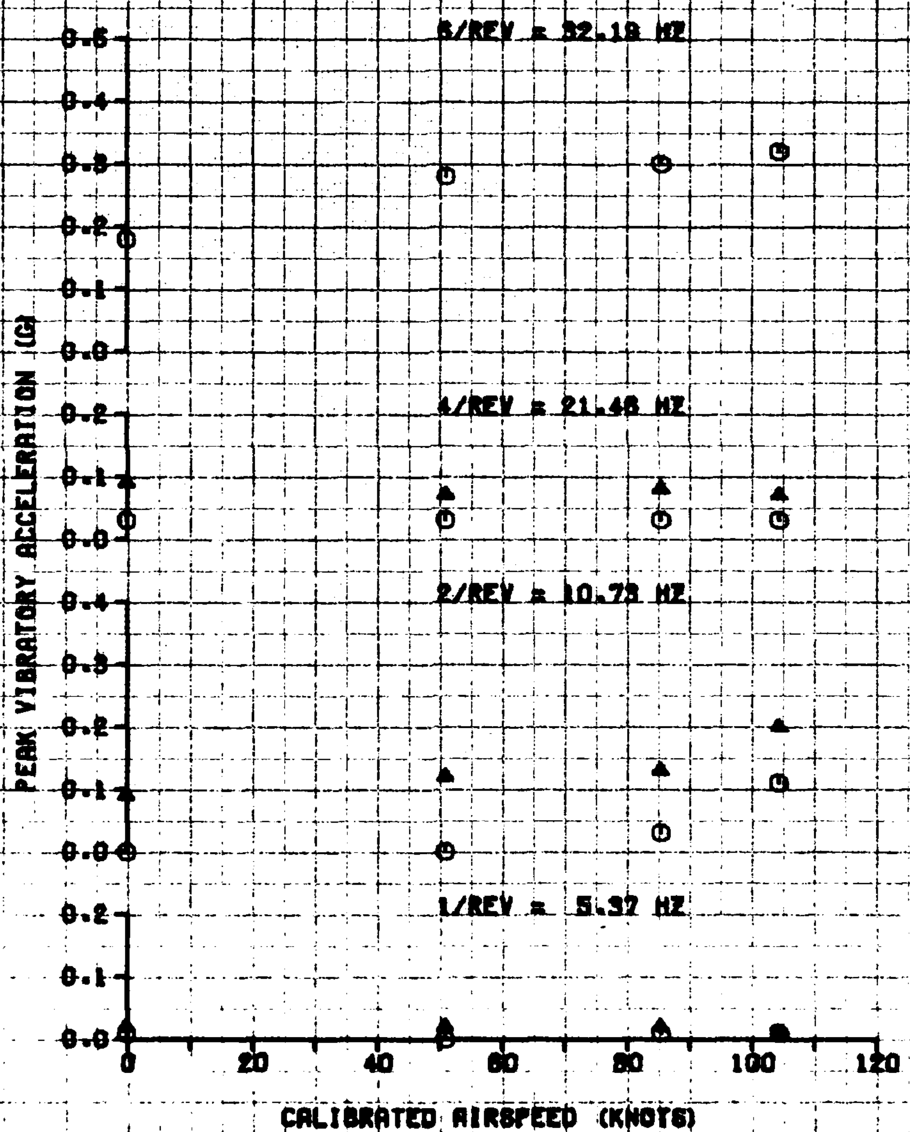
JUH-1H USA S/N 68-15532

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALT (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)
8080.	138.8(MID)	-.5(LT)	6140.	6.5	322.

DATA SOURCE:

○ SPECTRAL DYNAMICS ANALYZER

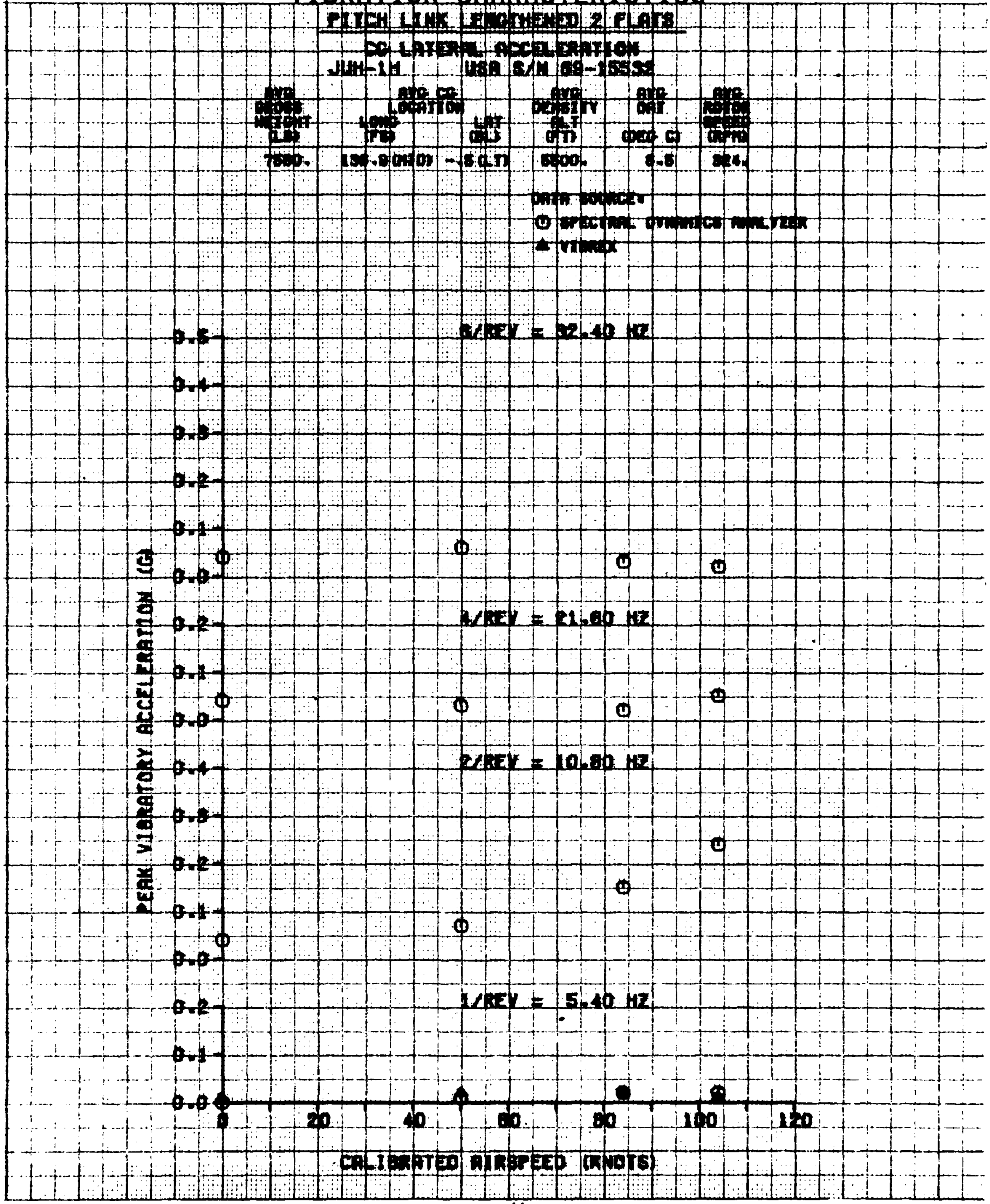
▲ VIBREX



FLT 81 VERT

FIGURE 6A

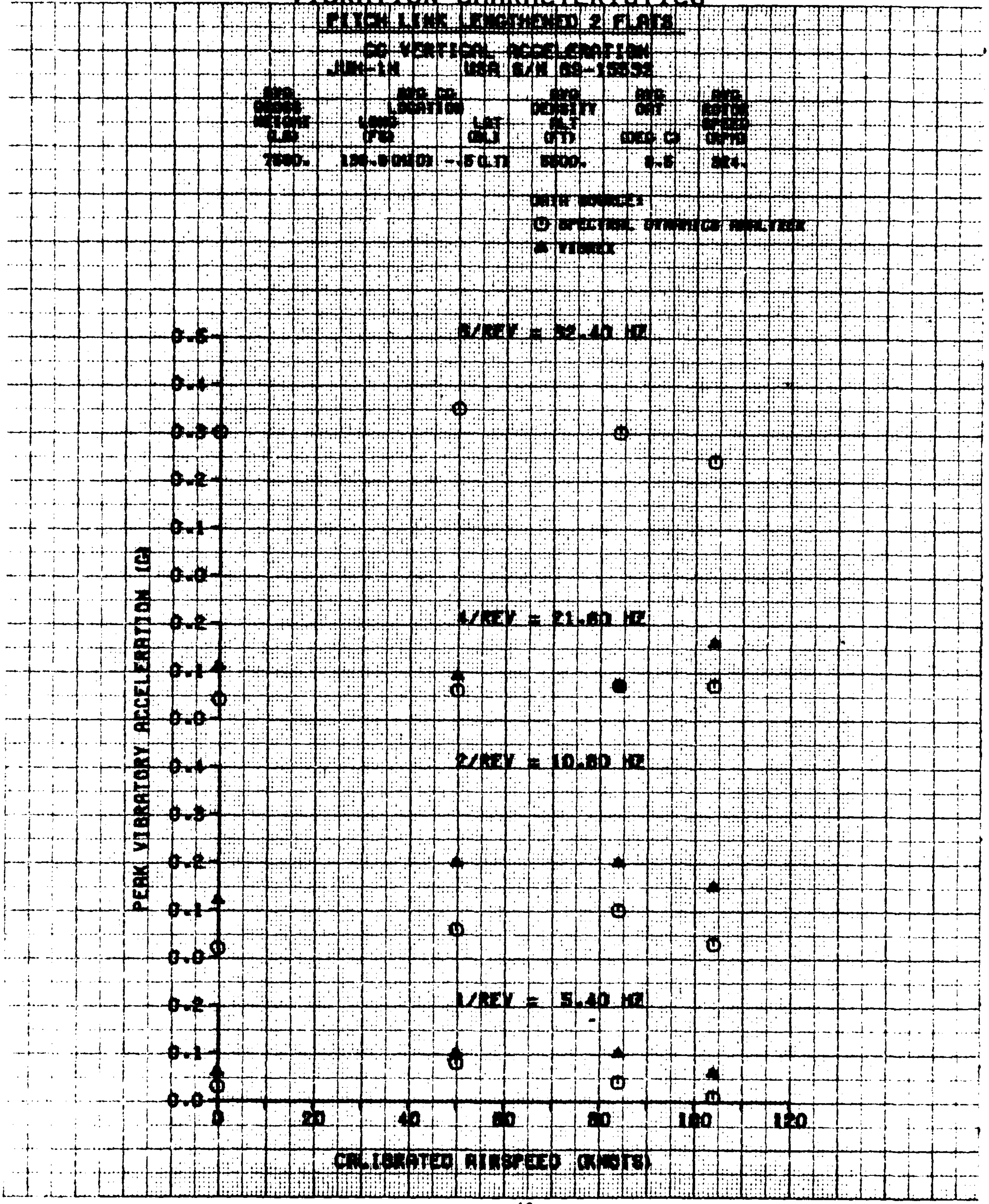
VIBRATION CHARACTERISTICS



FLT 52 LAT

FIGURE 6B

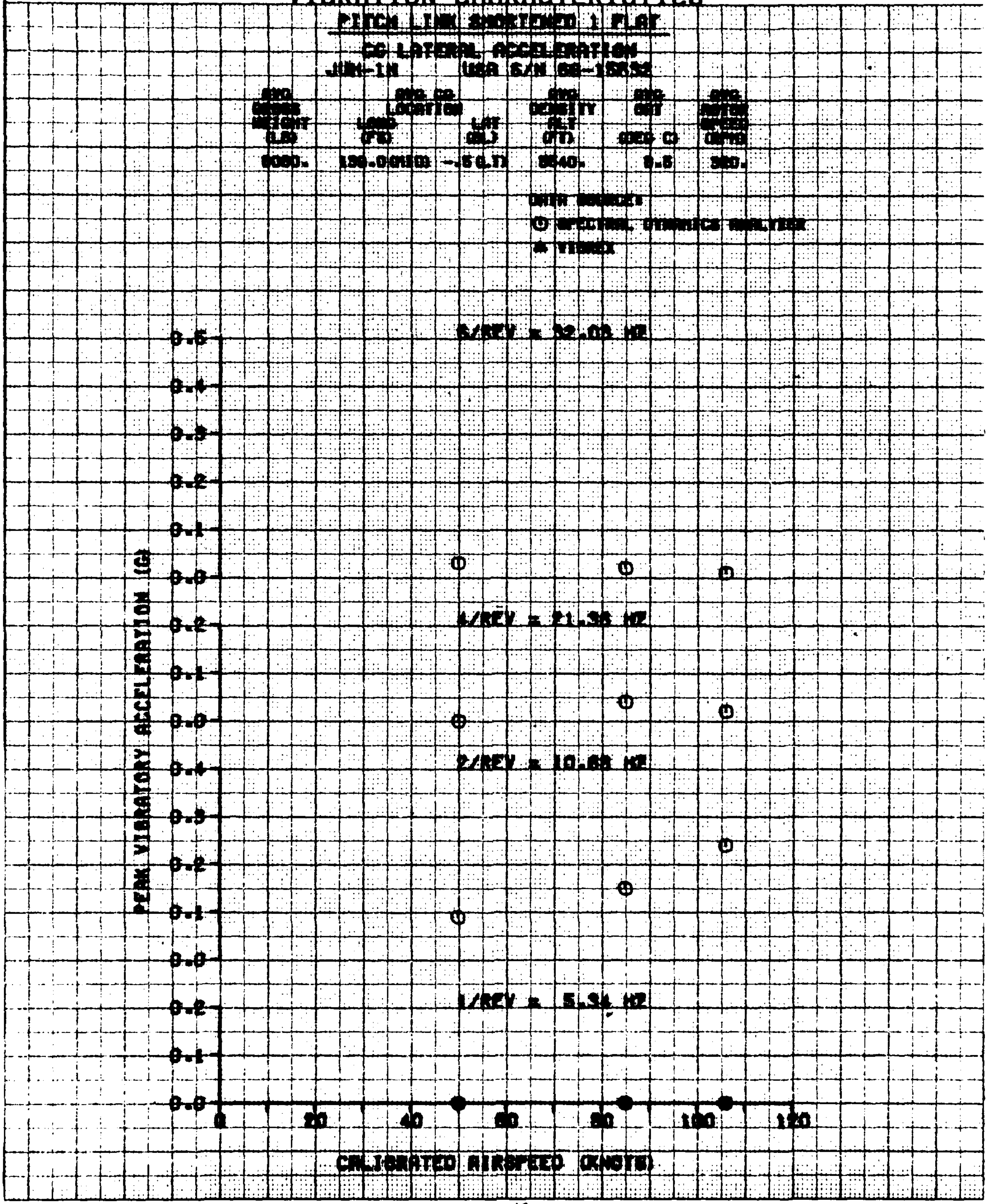
VIBRATION CHARACTERISTICS



FLT 52 VERT

FIGURE 7A

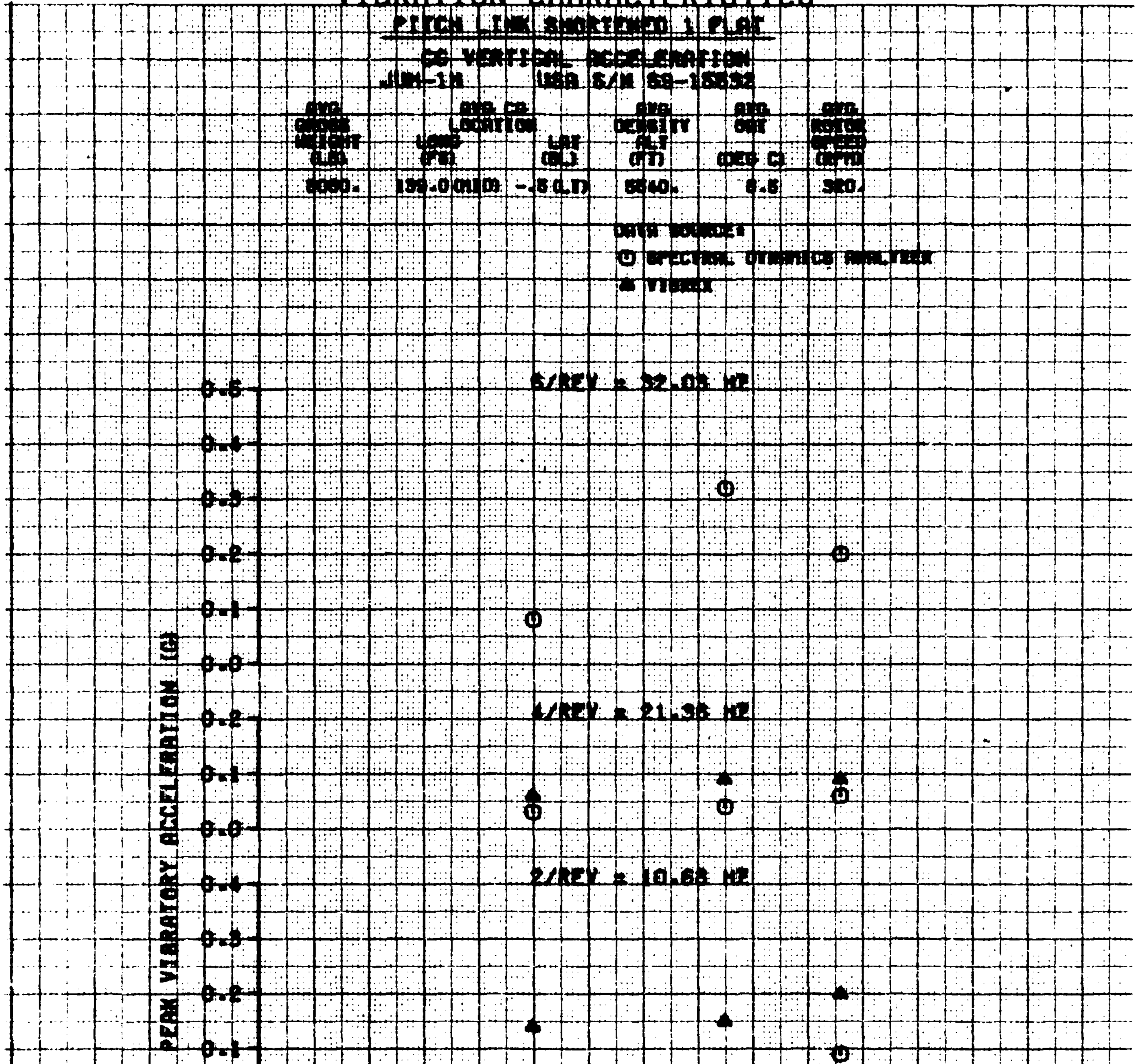
VIBRATION CHARACTERISTICS



FLT 63 LAT

FIGURE 7B

VIBRATION CHARACTERISTICS



FLT 63 VERT

FIGURE 8A

VIBRATION CHARACTERISTICS

PITCH LINK SHORTENED 1 FLAT

CG LATERAL ACCELERATION

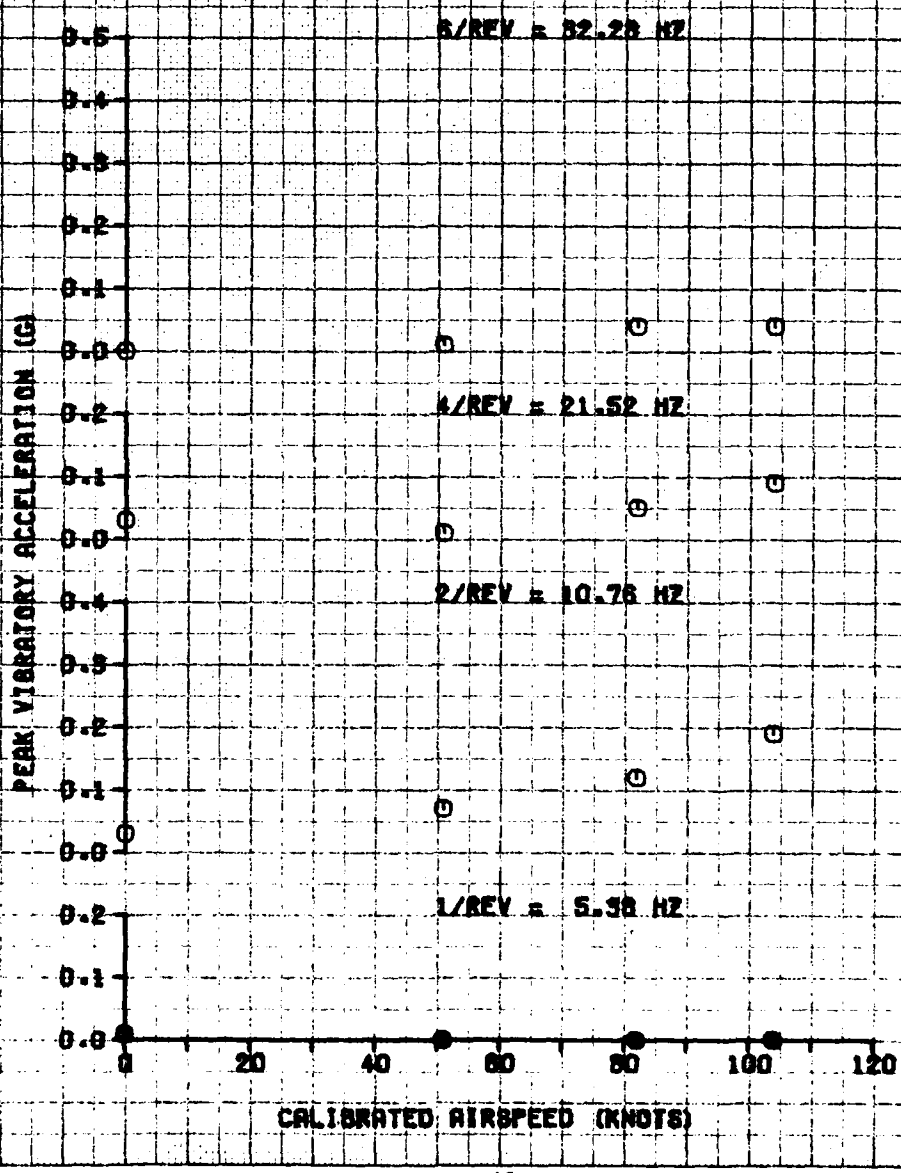
JUH-1H USA S/N 69-15532

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALT (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)
8010.	138.8(MID)	-.5(LT)	4940.	8.0	323.

DATA SOURCE:

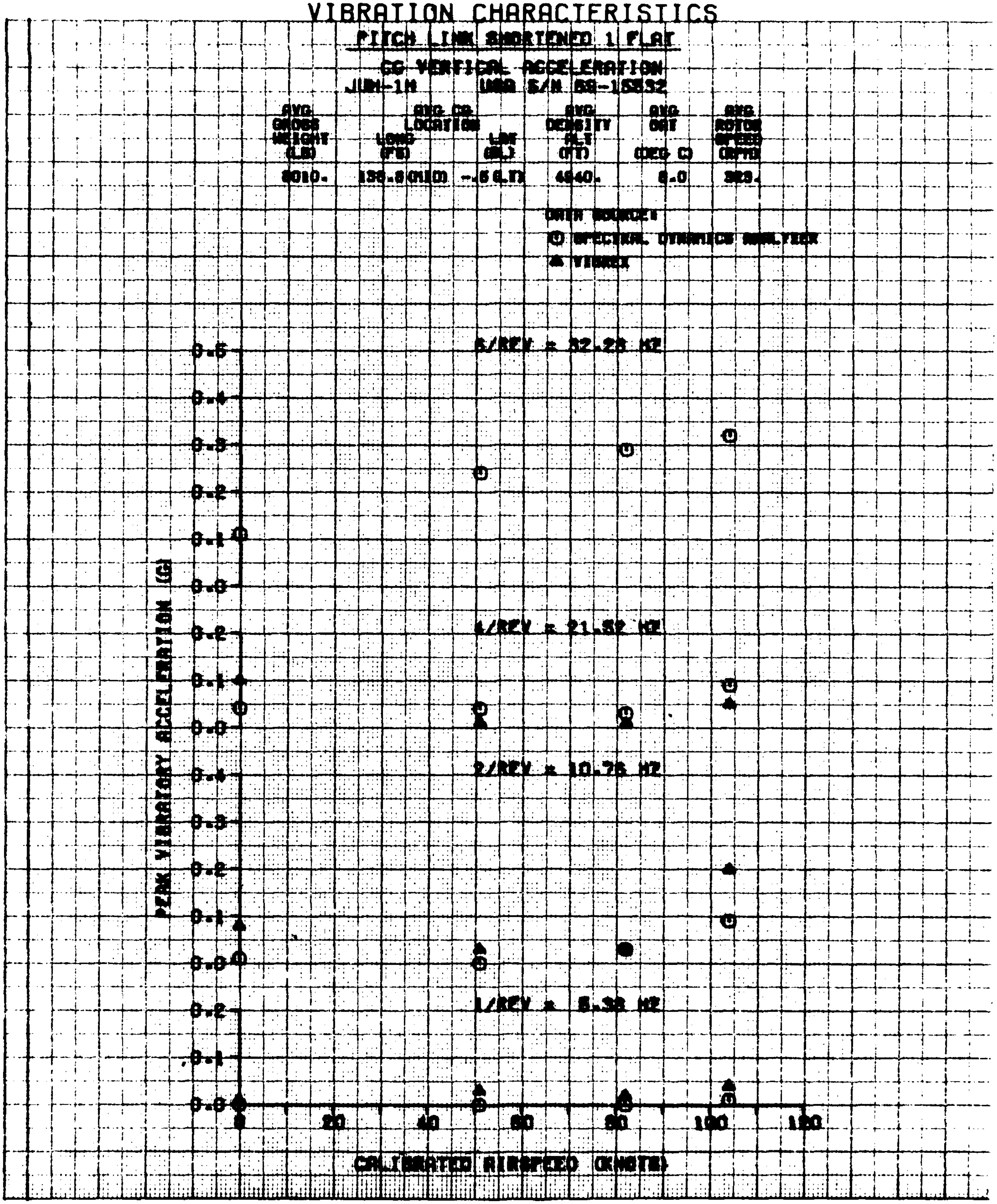
⊙ SPECTRAL DYNAMICS ANALYZER

▲ VIBREX



FLT 54A LAT

FIGURE 8B
VIBRATION CHARACTERISTICS



FLT 64A VERT

FIGURE 9A

VIBRATION CHARACTERISTICS

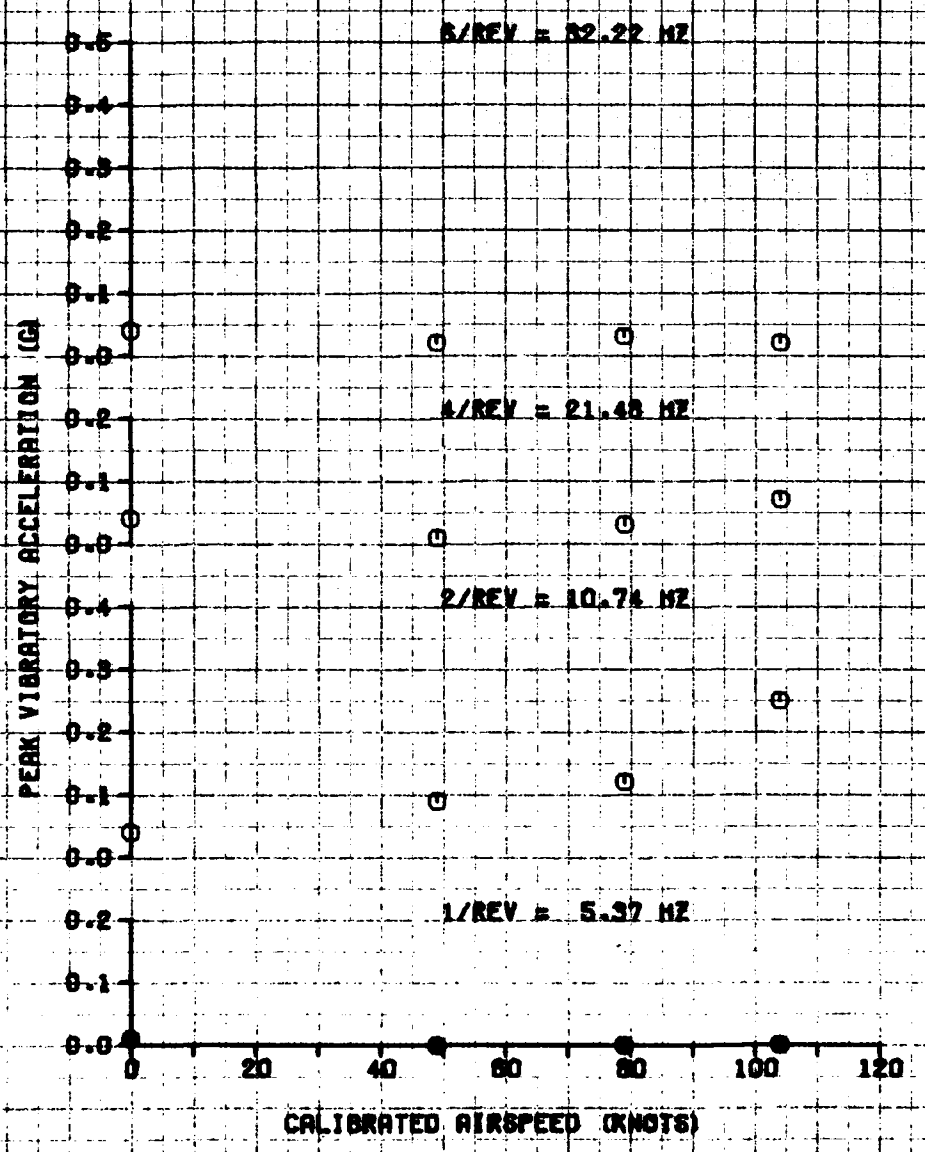
PITCH LINK LENGTHENED 3/4 FLAT

CG LATERAL ACCELERATION

JUH-1H USA S/N 69-15532

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG DENSITY ALT (FT)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)
8010.	130.8 (MID)	-.5 (LT)	5180.	10.5	322.

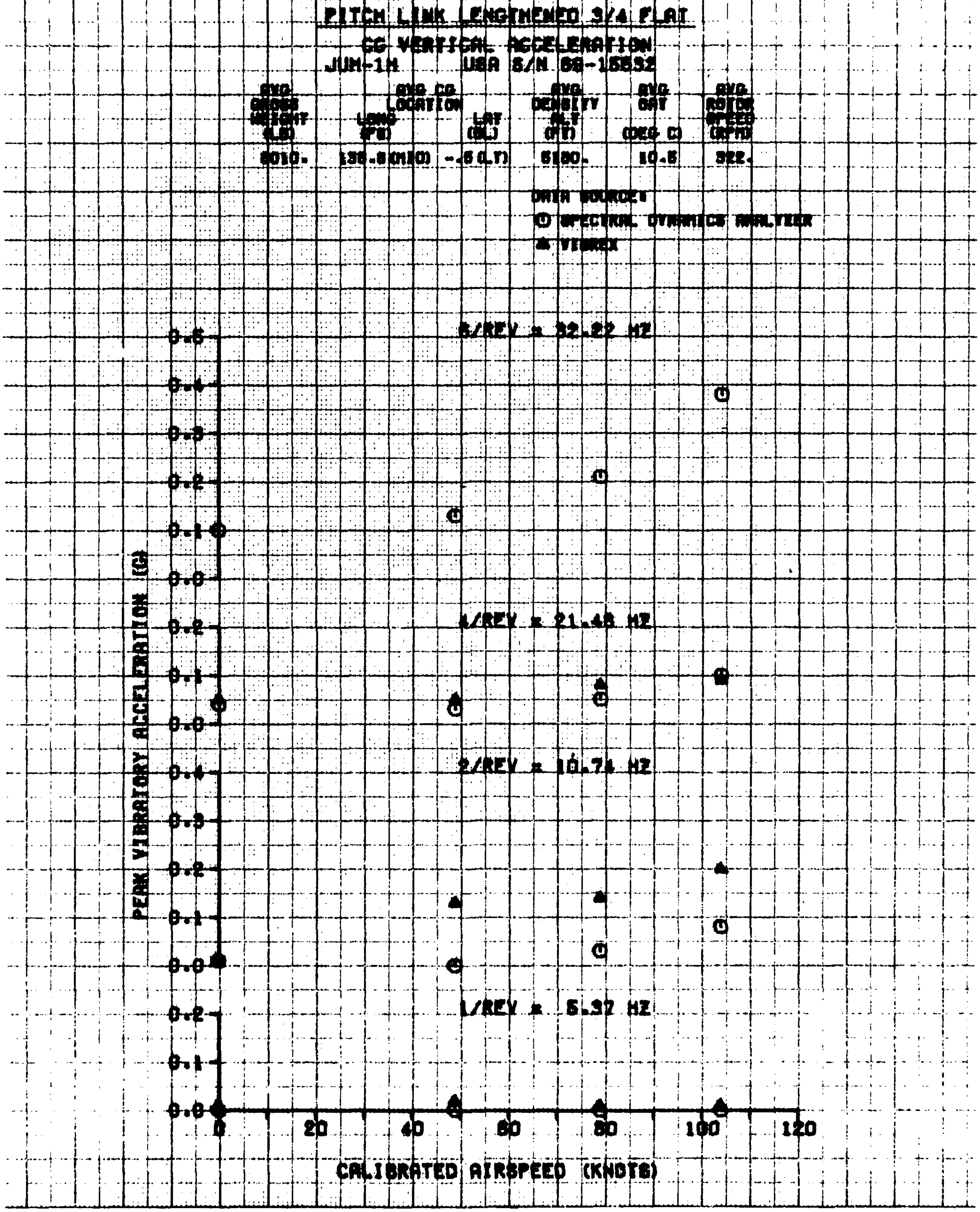
DATA SOURCE:
⊙ SPECTRAL DYNAMICS ANALYZER
▲ VIBREX



FLT.548 LAT

FIGURE 9B

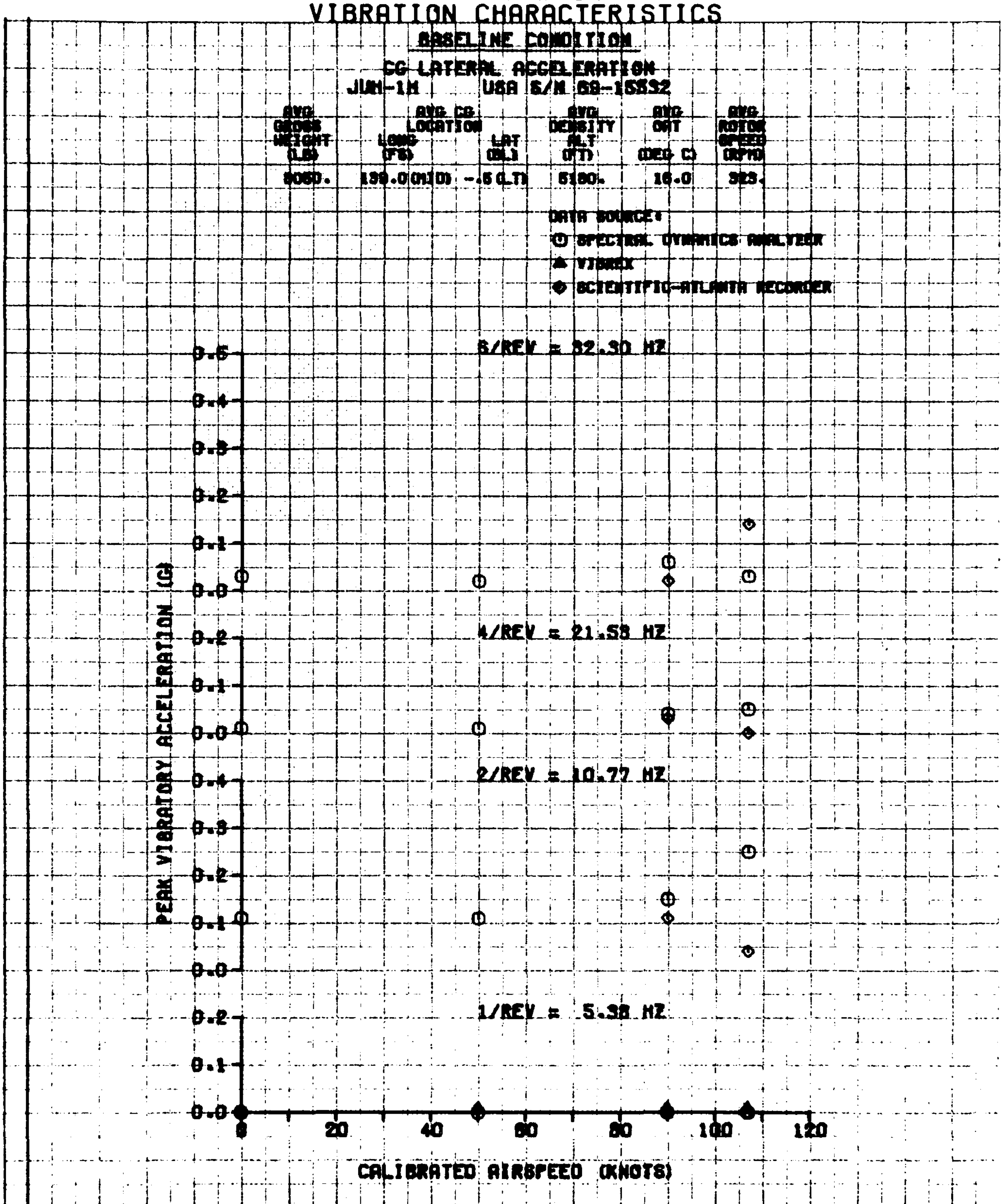
VIBRATION CHARACTERISTICS



FLT 548 VERT

FIGURE 10A

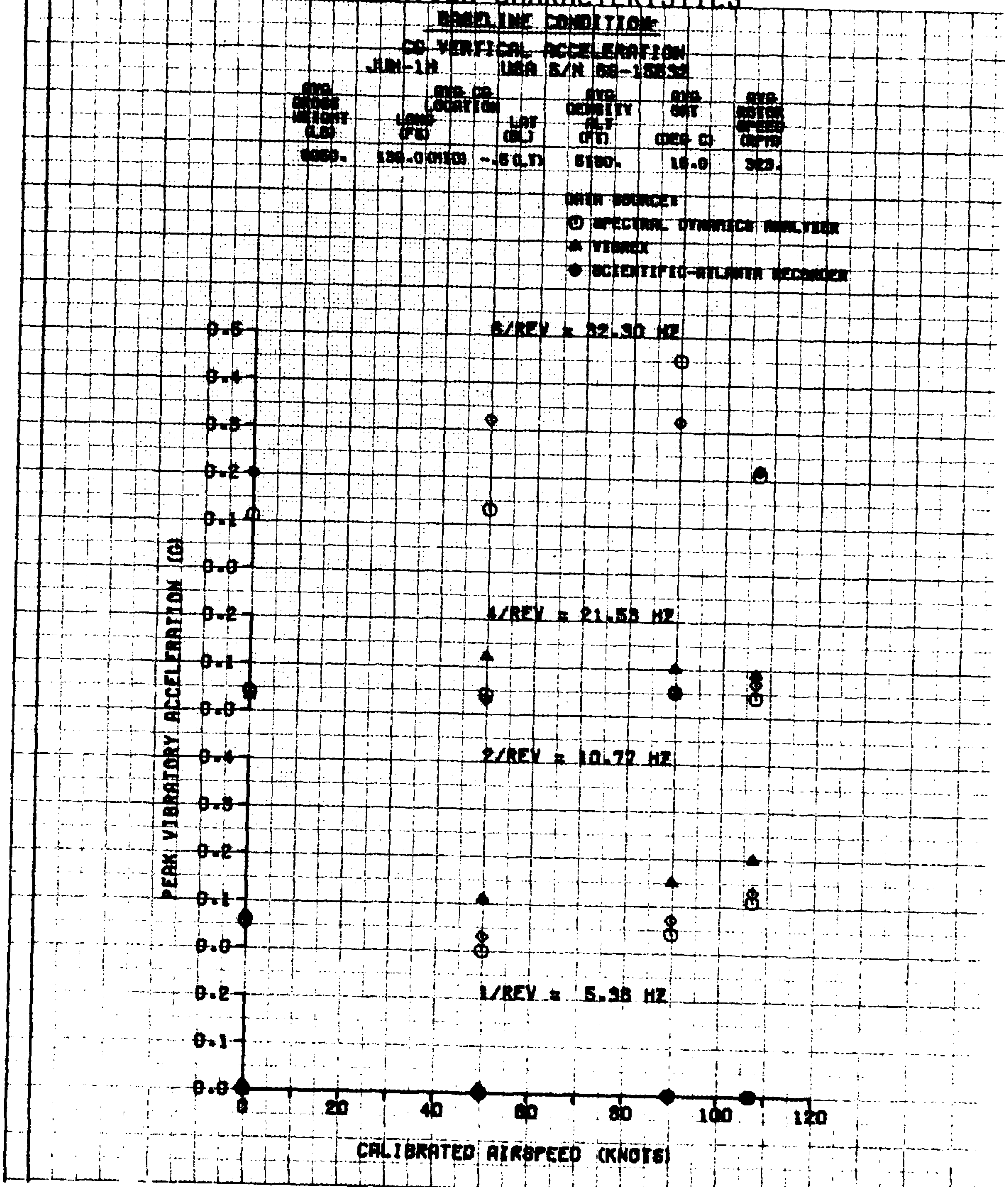
VIBRATION CHARACTERISTICS



FLT 55 LAT

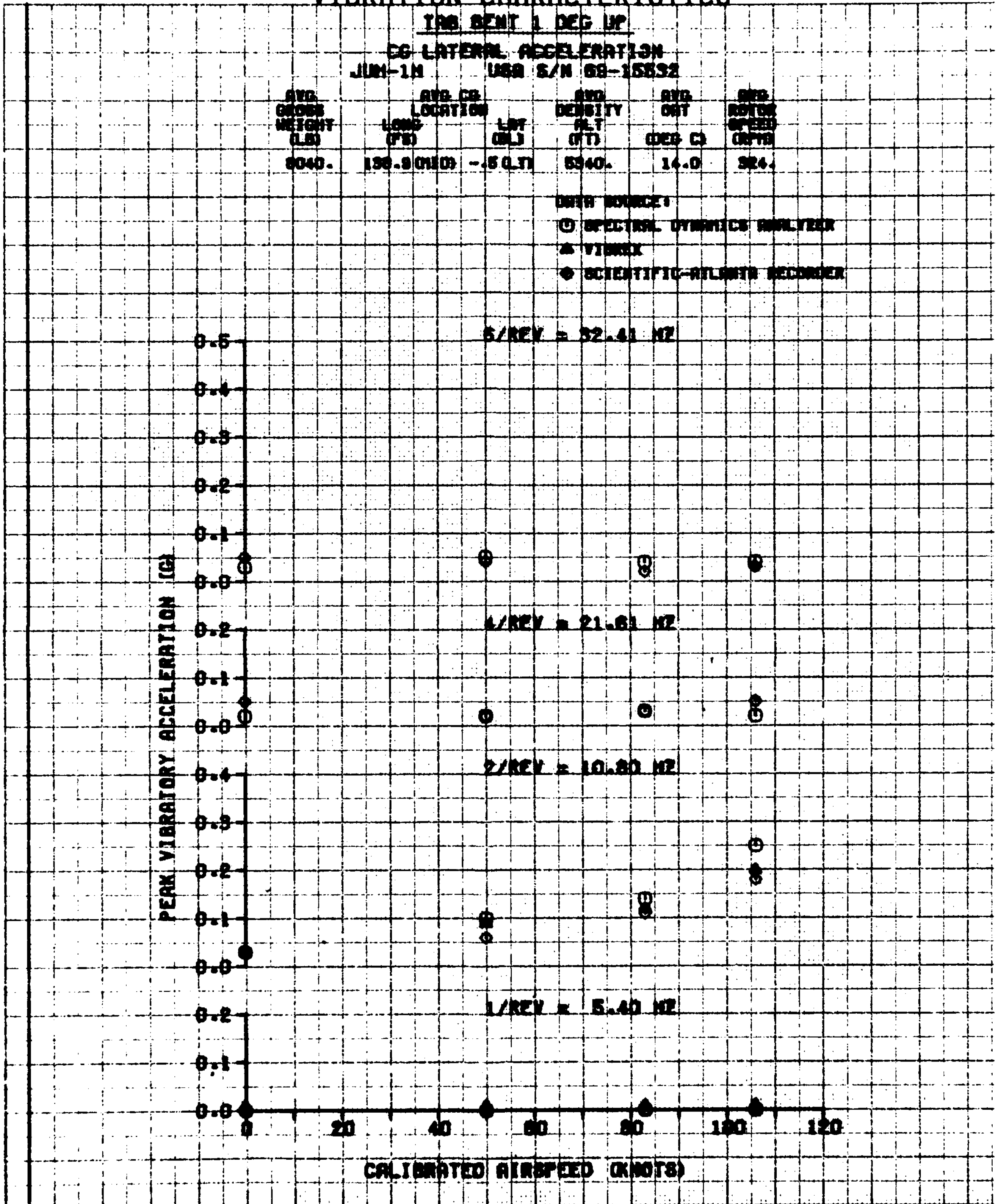
FIGURE 108

VIBRATION CHARACTERISTICS



FLT 55 VERT

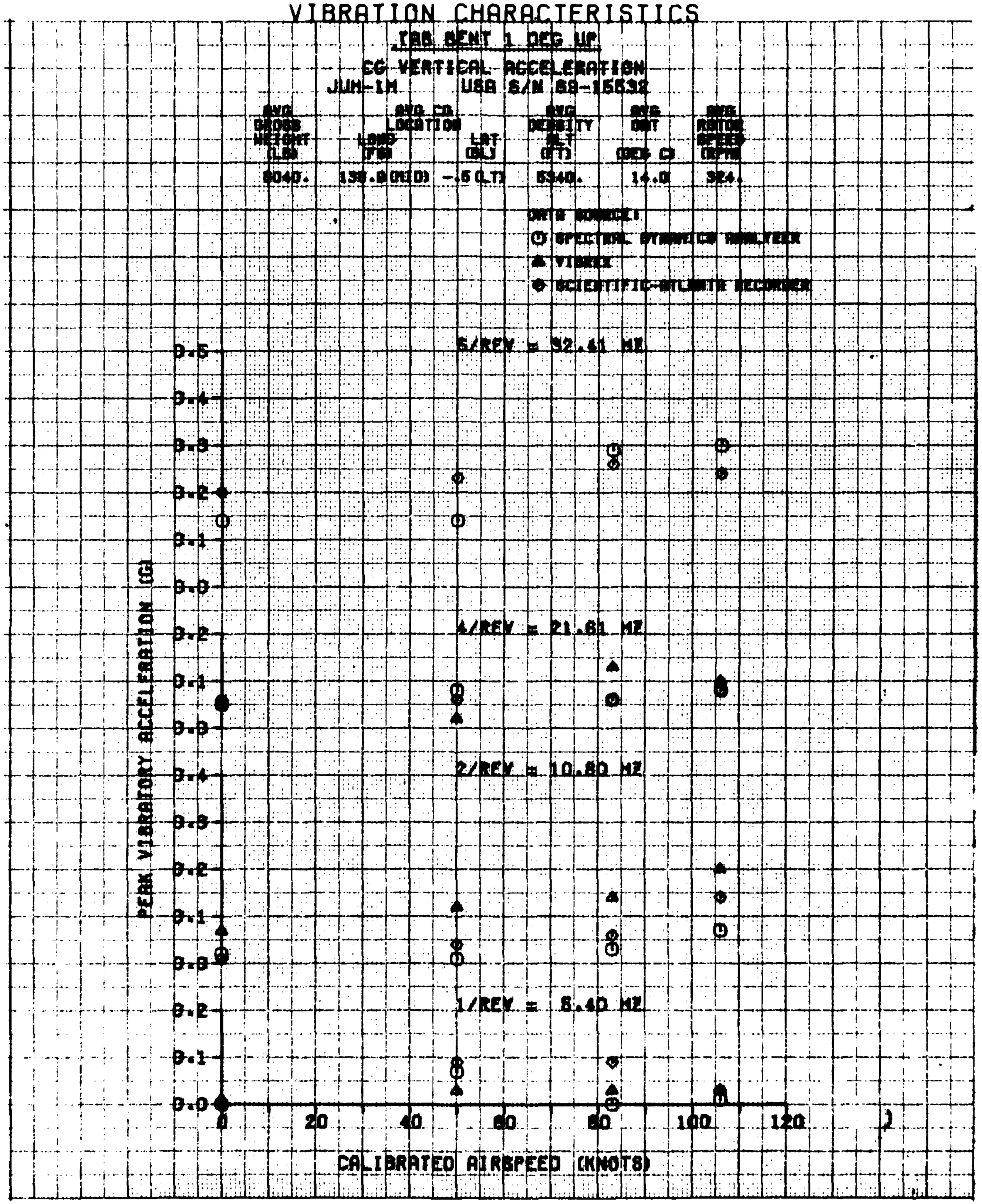
FIGURE 11A
VIBRATION CHARACTERISTICS



FLT 88A LAT

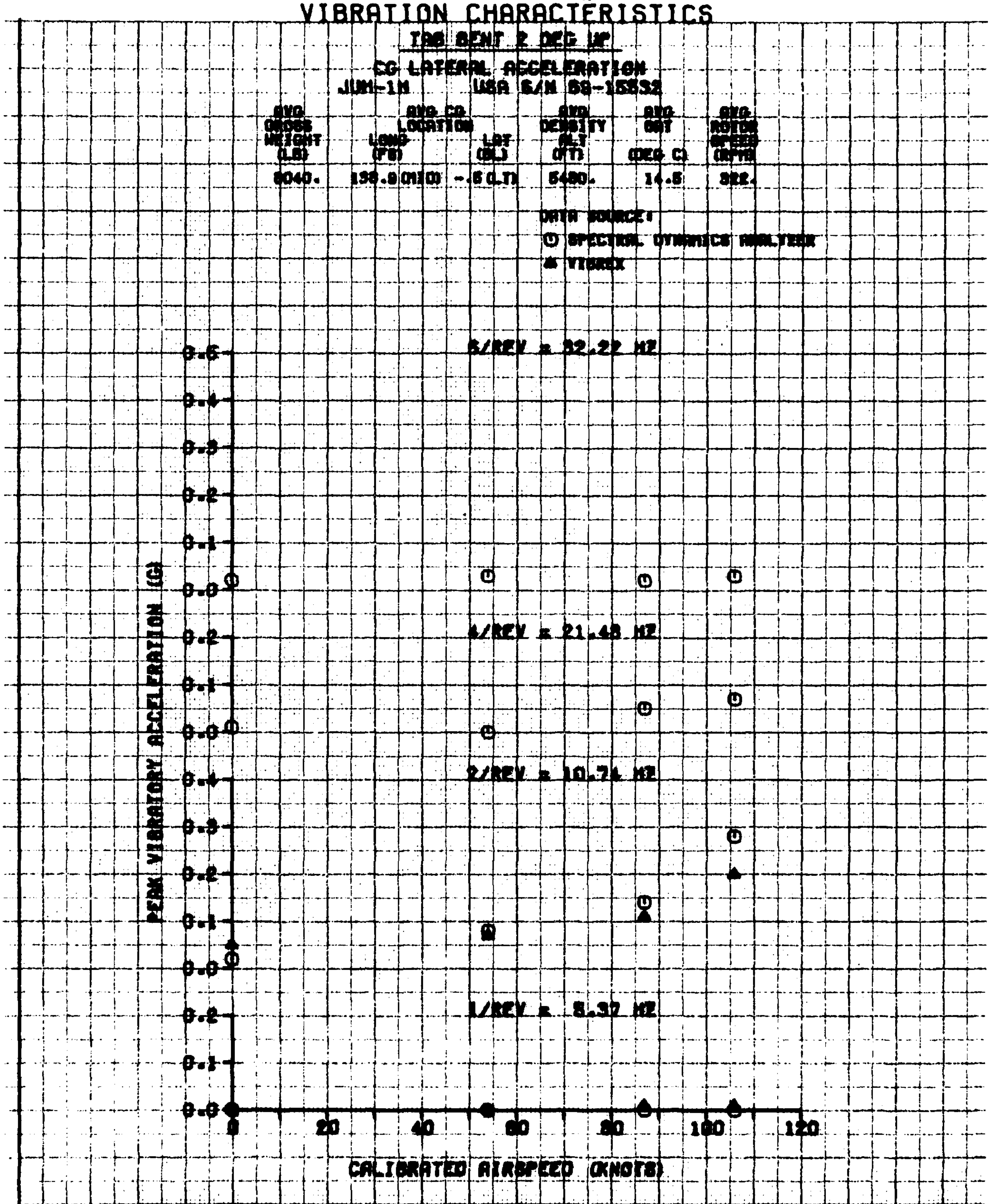
FIGURE 11B

VIBRATION CHARACTERISTICS



FLT 50A VERT

FIGURE 12A
VIBRATION CHARACTERISTICS



FLT 808 LAT

FIGURE 128

VIBRATION CHARACTERISTICS

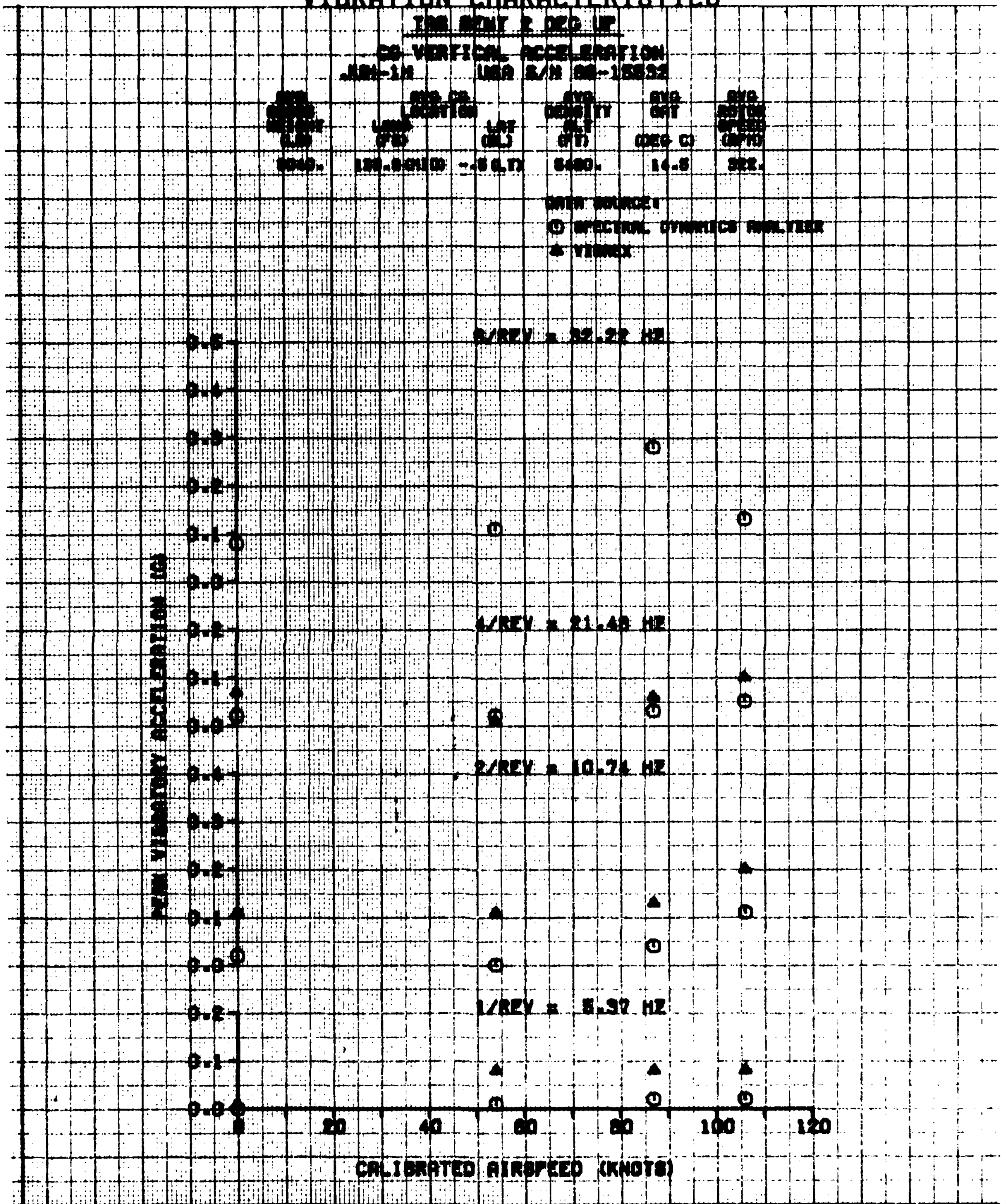
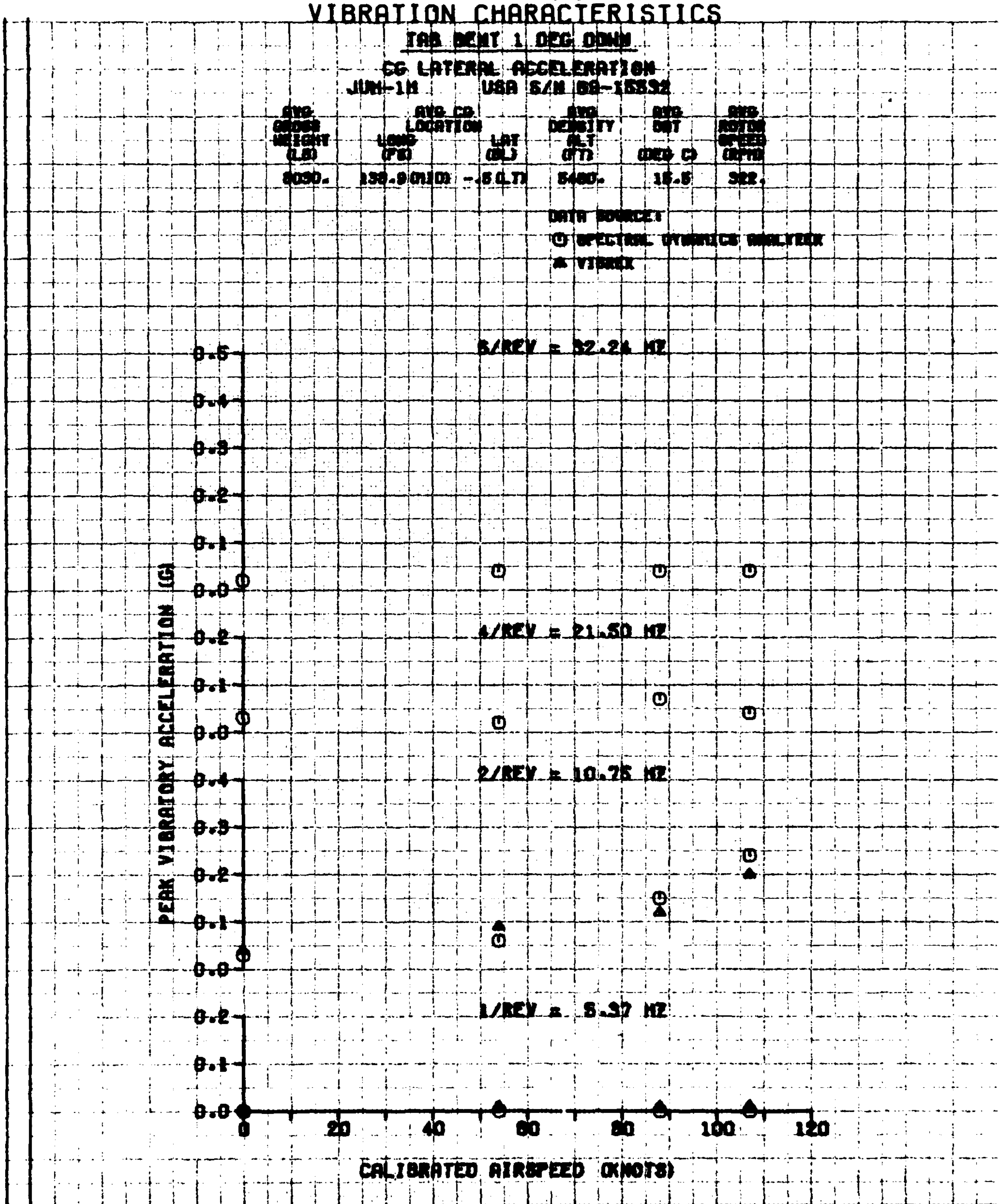
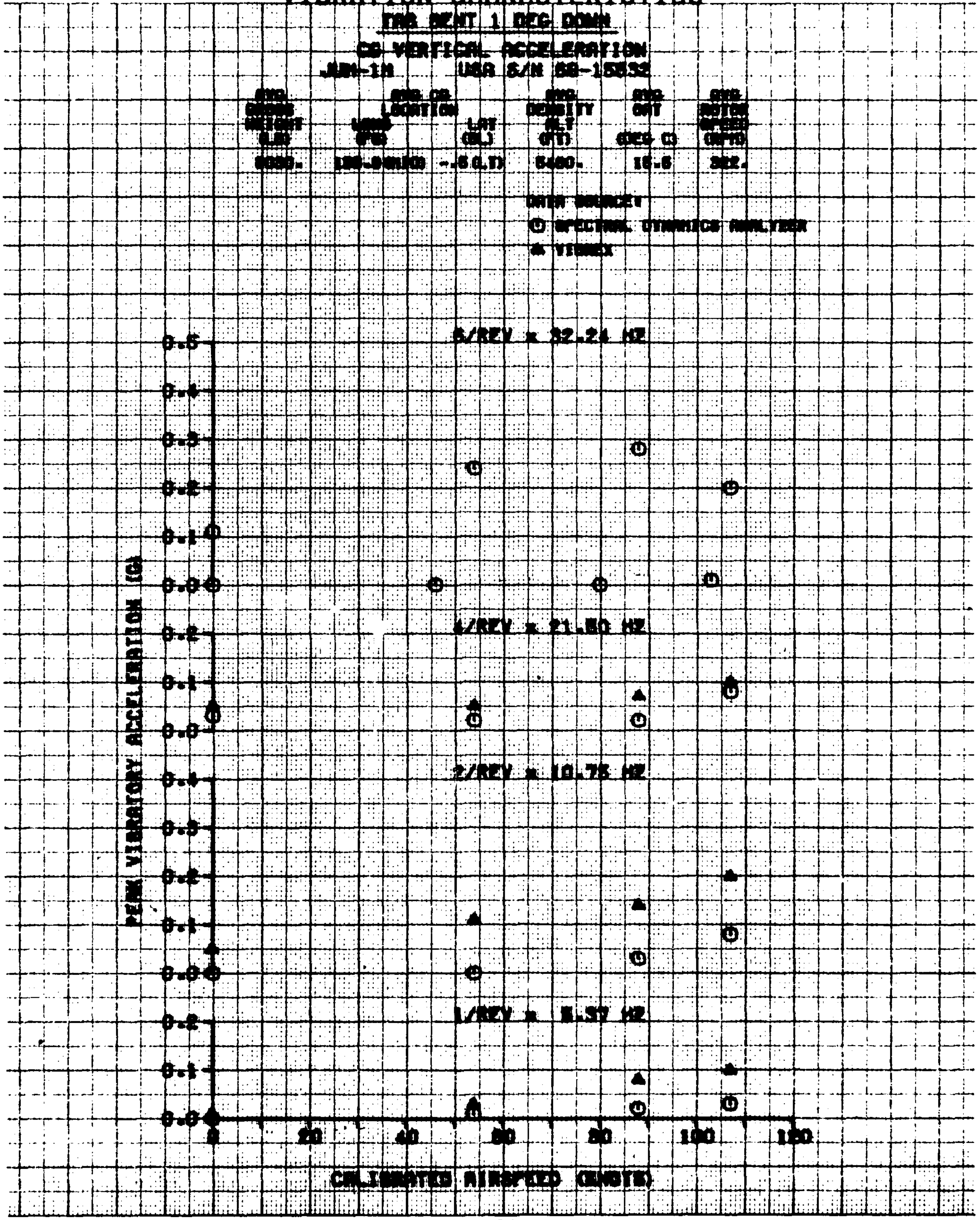


FIGURE 13A
VIBRATION CHARACTERISTICS



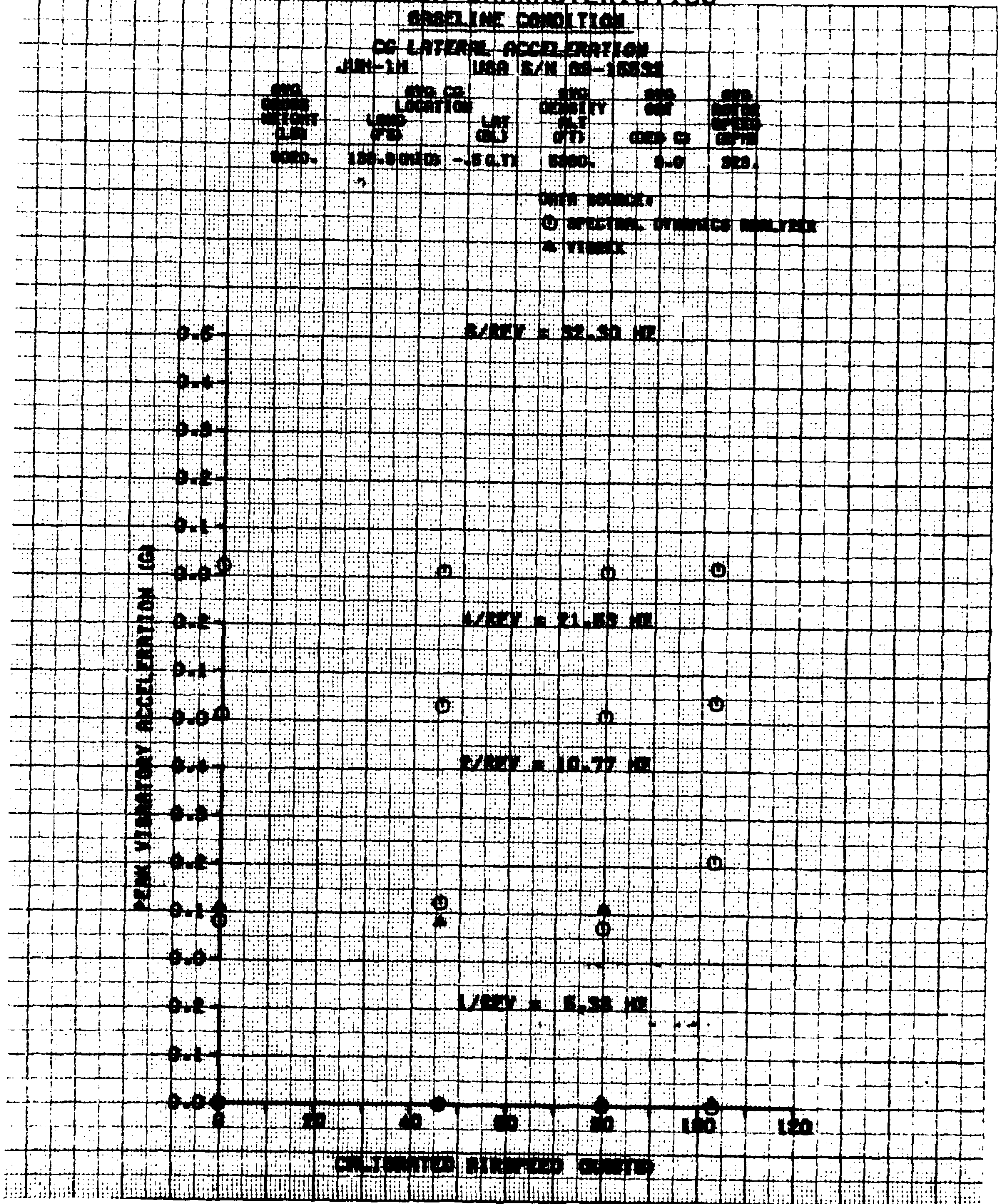
FLT 57A LAT

FIGURE 138
VIBRATION CHARACTERISTICS



FLT 87A VERT

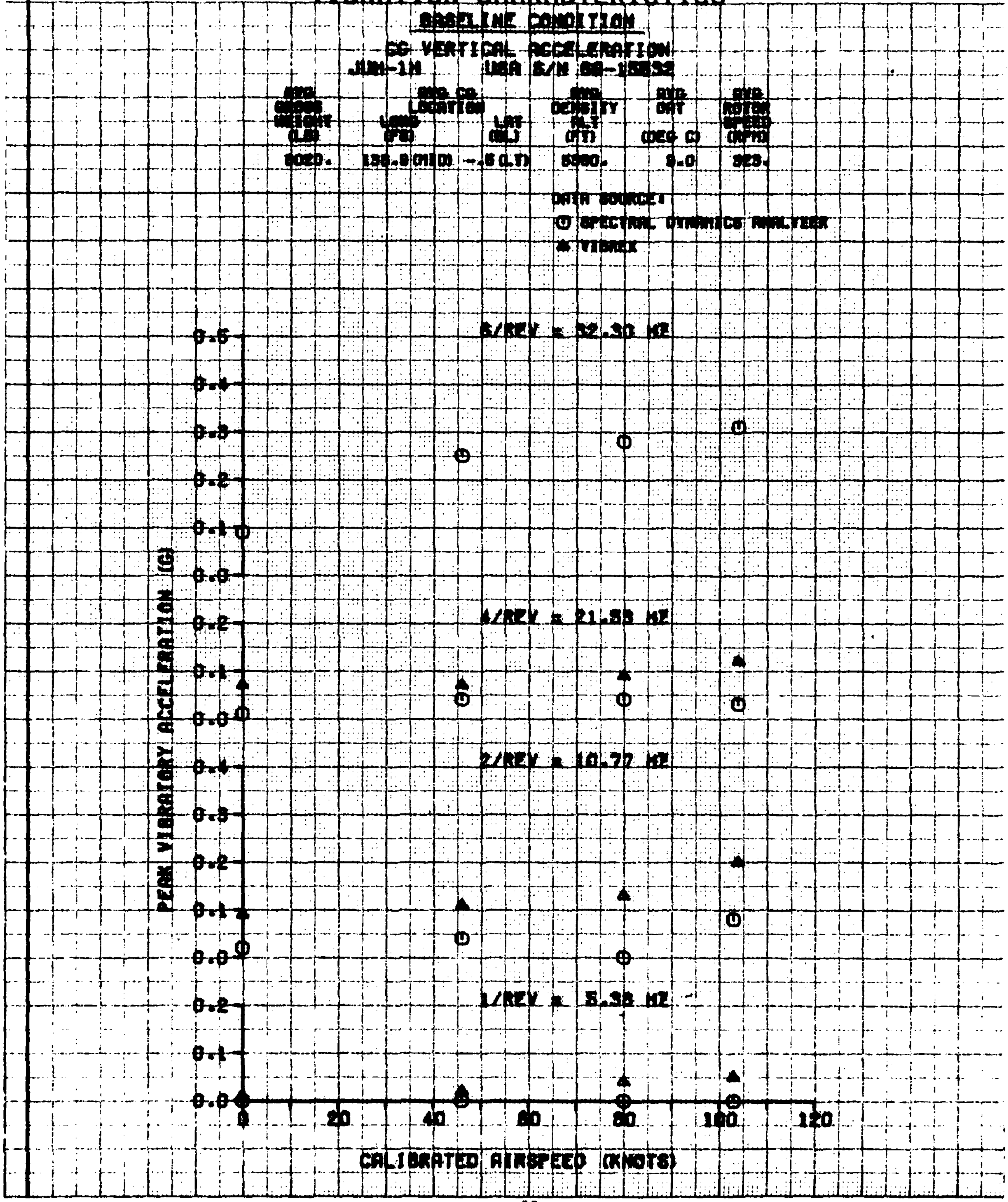
FIGURE 14A
VIBRATION CHARACTERISTICS



FLT 80 LAT

FIGURE 14B

VIBRATION CHARACTERISTICS



FLT 68 VERT

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